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THE ENVIRONMENTAL EFFECTS OF SEA WATER FISH FARMS

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FOREWORD

There has been considerable uncertainty regarding the effect that fish farms may have on the marine environment. This study was carried out at the request of the Norwegian Pollution Inspection Service (Statens forurensingstilsyn) to study these effects in more detail.

The work was chiefly carried out at commercial fish farms. We wish to thank the fish farmers that freely have placed operational data at our disposal. We also wish to thank cand. real. Asbjörn M. Stensvold and cand. real. Jens Petter Aabel who have participated in working up the benthic fauna material.

This report includes all the data collected in this study in order for these to be used for other purposes.

ABSTRACT

AURE, J., ERVIK, A.S., JOHANNESSEN, P.J. and ORDEMANN, T. 1988.
Resipientpåvirkning fra fiskeoppdrett i saltvann.
(The environmental effects of sea water fish farms).

The primary purpose of the investigation is to determine the extent to which fish farms in the sea influence the water masses and the benthic conditions around the farm.

Field investigations have been carried out at nine fish farms in Norway (SørTrøndelag and Hordaland) located in closed or protected areas. The farms varied in the amount of fish produced and the type of food used. The background data on operational practices, hydrography, topography and current were taken from the NFFR-funded project "Pollution in marine aquaculture" carried out by the Institute of Marine Research. Examinations of the sediment and the benthos were conducted at all nine farms. At two of the farms, there were additional analyses of nutrient salts and sedimentation of organic material in open water and the littoral zone.

Nutrient salts Analyses of the nutrient salts showed that the area around the fish farms was only slightly affected. In some cases there was an increase in the amount of phosphorus and nitrite in the water close to the farm. No elevated values of nitrate or silicate were found, neither in nor around the fish farms, irrespective of operational practices. Other investigations show that the concentration of ammonium can be strongly influenced by fish farming, whereas this investigation revealed a 2 to 9-fold increase limited to the immediate vicinity of the farm.

Sedimentation rates and sediment composition

The sedimentation rates were not higher than those found in other, unfarmed areas. Sedimentation rates in the upper 25m within 100-200m distance of the farm were, however, higher than further out in the recipient. This was also the case for concentrations of total organic material, organic carbon, organic nitrogen and total particulate phosphorus. During the spring bloom high values of chlorophyll were found in the area of the farm.

Elevated rates of sedimentation were occasionaly found in the upper water column during periods of heavy feeding. There was very little influence on the sedimentation about 250m from the farm, where the sedimentation was in fact lower than normal. There was also no influence from the farming on the benthos of a deep basin.

There was, however, an increase in the C/N ratio in the sediment over the entire area of investigation. This indicates that the sedimented material

was quite decomposed, probably by increased biological activity around the fish farm. The increase in sedimentation rates and C/N ratio was most clearly observed in sheltered areas with dense farming.

The sedimentation rates around the farm (100m) were only 0.2% of those usually found under the farms. This implies that most of the organic waste from fish farming settles within the farm area when current are weak and depths are moderate (10-20m).

Benthos and Sediment Investigations

The bottom fauna is affected by the farms. The influence is, however, restricted to the immediate vicinity of the fish farms and is further determined by the bottom topography, hydrography and current regime as well as the type of food, amount of overfeeding and the quantity of fish produced.

At farms with an uncomplicated bottom topography and steady currents it was apparent that the degree of impact was dependent on the distance from the source. Under such conditions, the impact displayed the classical pattern of a polluted, a stimulated and an unaffected zone according to distance from the farm.

At other farms the impact was less clear, depending more on the bottom topography and the current and less on distance. One farm which used wet feed had an insignificant impact on benthos and sediment both in and around the farm. The wet feed was, in this case, quickly reduced to small particles and dispersed over a large area.

The investigations have also shown that high concentrations of organic material in the sediment are not necessarily correlated to an impoverished fauna. Thus, low concentrations of organic material are not automatic indications of good bottom conditions. Investigations of benthic fauna appear to be the most sensitive method to date for monitoring environmental impact from fish farms.

Littoral Zone Investigations

The environmental impact of fish farming was relatively modest on the littoral zone. An increase in the number of annual green algae was found inside the farms, but this effect did not stretch further than 20-30m from the farm, where the littoral community seemed normal.

Oxygen content

Changes in the oxygen content are also limited to the farm area or to adjacent, small sill areas. The average oxygen content within a farm was usually 10% lower than in uninfluenced areas. In some cases oxygen values just above the sediment could be 30% lower than normal.

Two of the farms investigated lay shoreward of sills, over about 80m depth. During stagnant periods the oxygen consumption in these two basins was from 0.8 to 1.0 ml/l per month. This is higher than the oxygen consumption in other comparable basins.

CONCLUSIONS

- the environmental impact of fish farming in the sea is limited to the immediate surroundings of the farm (in recipients with no sills or shallow areas).

- nutrient salts and small organic particles seem to be transformed quickly close to the farm. Physical mixing processes also contribute to the rapid reduction in concentration levels within a short distance from the farm.

- monitoring the environmental conditions around fish farms is best done through the use of bottom fauna and sediment investigations. It is also possible that elevated values of the C/N ratio in the water column can give an indication of increased loading over a larger area.

- monitoring the oxygen consumption in the bottom water of basins with shallow sills may also give early indications of increased loading from fish farms located in such areas.

- the environmental impact of fish farming is modest compared to its theoretical release of nutrient salts and organic compounds. This may be because much of this is bound to larger particles (feed and fecal pellets) which may be consumed immediately or sediment to the bottom directly under the farm.

Waste from fish farms cannot be directly compared with sewage. Sewage releases most of the nutrient salts in a dissolved form, while much of the organic particulate matter has a low sinking rate. Thus much of the sewage components are transformed immediately in the water in the form of plankton production. Sewage will also contain other components and toxic compounds which can harm the biota in the recipient.

2. INTRODUCTION

In recent years there have been increasing concerns expressed as to the extent the waste products from fish farms affect benthic conditions and the water masses in the vicinity of the farms.

In order to obtain more information on these conditions, studies were carried out at 9 fish farms. The project is coordinated with the NFFR - project "Pollution, marine aquaculture" being undertaken by the Institute of Marine Research, Bergen. The last mentioned project is concerned with studying the environmental conditions in and in the immediate areas around fish farms, and has as the principal objective to clarify the importance of the environment as a factor in production.

The study consists of four major elements:

1. Nutrient salt concentrations in the winter season in and around 2 farms.
2. Sedimentation of organic material near 2 farms (1 year cycle)
3. Benthic animal - and bottom sediment studies at 9 farms.
4. Littoral zone studies at 2 farms.

The project was commissioned by the Norwegian Pollution Inspection Service (Statens forurensingstilsyn, SFT) as a cooperative project between the (Directorate of Fisheries) Institute of Marine Research, Nordnes, Bergen and the Institute for Marine Biology, the University in Bergen. The project leader has been Jan Aure, Institute of Marine Research.

The project was financed by SFT, the Fish Farmers Marketing Cooperative (Fiskeoppdretternes Salgslag A/L (FS)) and the Institute of Marine Research.

3.DESCRIPTION OF LOCALITIES AND INSTALLATIONS.RECORDING STATIONS.

Data used in this section are taken from the NFFR (Norwegian Fisheries Research Council) project "Pollution - Marine Aquaculture".

3.1. Topography and recording stations

The farms studied (nine) are located in sheltered and enclosed waters. Four of the farms are in the county of Sör Tröndelag and five in Hordaland county.

Farm 1 (Fig. 3.1)

Farm 1 is located in a sound with a water depth of 8-10 m at the installation. The greatest depth in the sound is ca 18 m, and there are no sills towards the open waters in a southwesterly direction.

The stations where benthic samples were taken are shown.

Farm 2 (Fig. 3.2)

The installation is located in a bay with a maximum water depth of ca 25 m. The depth to the sill in the basin is ca 17 m. Under the farm itself the depth varies between 7 and 15 m.

Stations for benthic sampling, hydrography, nutrient salts and sedimentation are shown.

Farm 3 (Fig. 3.3)

This installation is located in a deep basin with a sill depth of 4-5 m in the eastern end. The greatest depth in the basin is ca 80 m and the surface area about 0.4 km^2. The farm is located in the western part near an inlet with a depth of ca 3m. The depth under the farm is between 10 and 30 m.

Stations for benthic sampling are shown.

Farm 4 (Fig. 3.4)

The installation is located in the sill area of a small bay (0.5 km²). The greatest depth in the bay is ca 40 m and the sill depth ca 20 m. The depth under the farm itself varies between 10 and 15 m.

Benthic sampling stations are shown.

Farm 5 (Fig. 3.5) (p.3)

The installation is located in a constrained area inside a number of small islets. The water depths under the farm vary from 8 to 11 m. In the north end of the bay there is a small depression of ca 11 m, while the sill depth out towards the open water is ca 24 m. The sill depth in to the bay is ca 8 m and the surface area ca 0.2 km².

Benthic sampling stations are shown.

Farm 6 (Fig. 3.6)

The installation is located in the inner part of a sound with a sill depth of ca 12 m and a deep area close to the farm of ca 20 m. The depths at the farm are between 10 m and 20 m. The sill depth towards the sound inside the farm is ca 8 m.

Benthic sampling stations are shown.

Farm 7 (Fig 3.1)

Farm 7 is located in a small bay where the water depth under the installation is 5-10 m. The area outside has a greatest depth of 25 m with a sill depth of 15 m.

Benthic sampling stations are shown.

Farm 8 (Fig. 3.7)

The installation is located in a small bay. The water depths increase from ca 10 m closest to shore to ca 25 m at outer edge of the farm. Just north of the farm there is a deep area with a depth of 40 m and with a sill depth of ca 30 m.

Benthic sampling stations are shown.

Farm 9 (Fig. 3.8)

West of the installation there is a deep basin with a maximum depth of ca 90 m. The outer sill depth is ca 30 m and the surface area about 0.7 km².

The water depth towards the enclosed areas to the south of the farm is ca 44m. The depths under the installation varies between 7 and 20 m.

The sampling stations for benthos, hydrography, nutrient salts and sedimentation are shown on the figure.

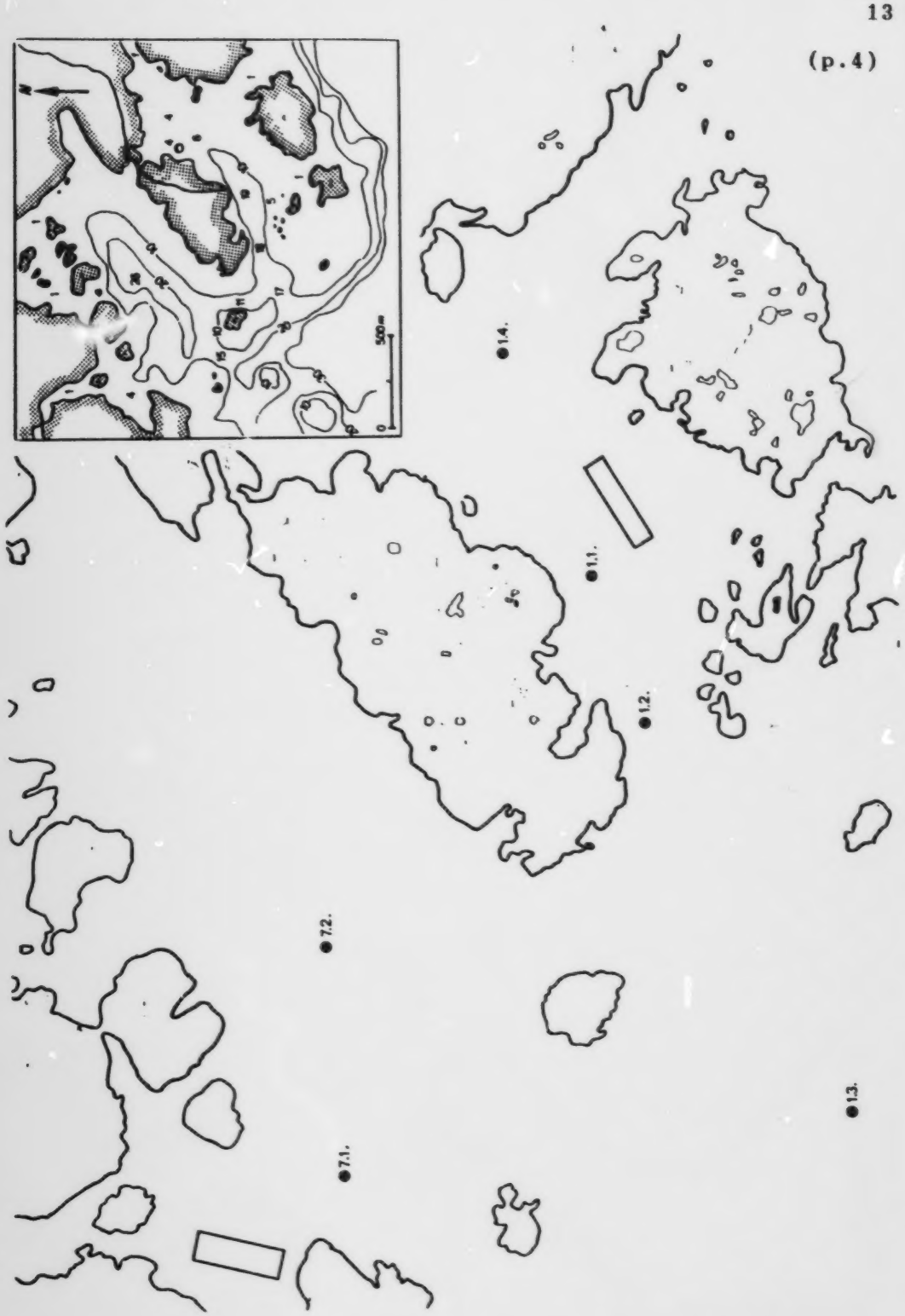

Fig. 3.1 Bunntopografi og lokalisering av anlegg og stasjoner for bunndyrundersøkelser ved anlegg 1 og anlegg 7. Anlegg 1 ligger lengst øst.

Bottom topography and locations of fish farms and benthos investigations at farm 1 and 7. Fish farm 1 lies most to the east.

Fig. 3.2 Bunntopografi og lokalisering av anlegg og undersøkelsesstasjoner ved anlegg 2. + - angir næringssaltundersøkelser, ▽ - angir sedimenteringsundersøkelser, ● - angir bunndyrundersøkelser.

Bottom topography and location of benthos investigations at fish farm 2. +, ▽, and ●, represent sampling stations for nutrients, sedimentation, and benthos investigations respectively.

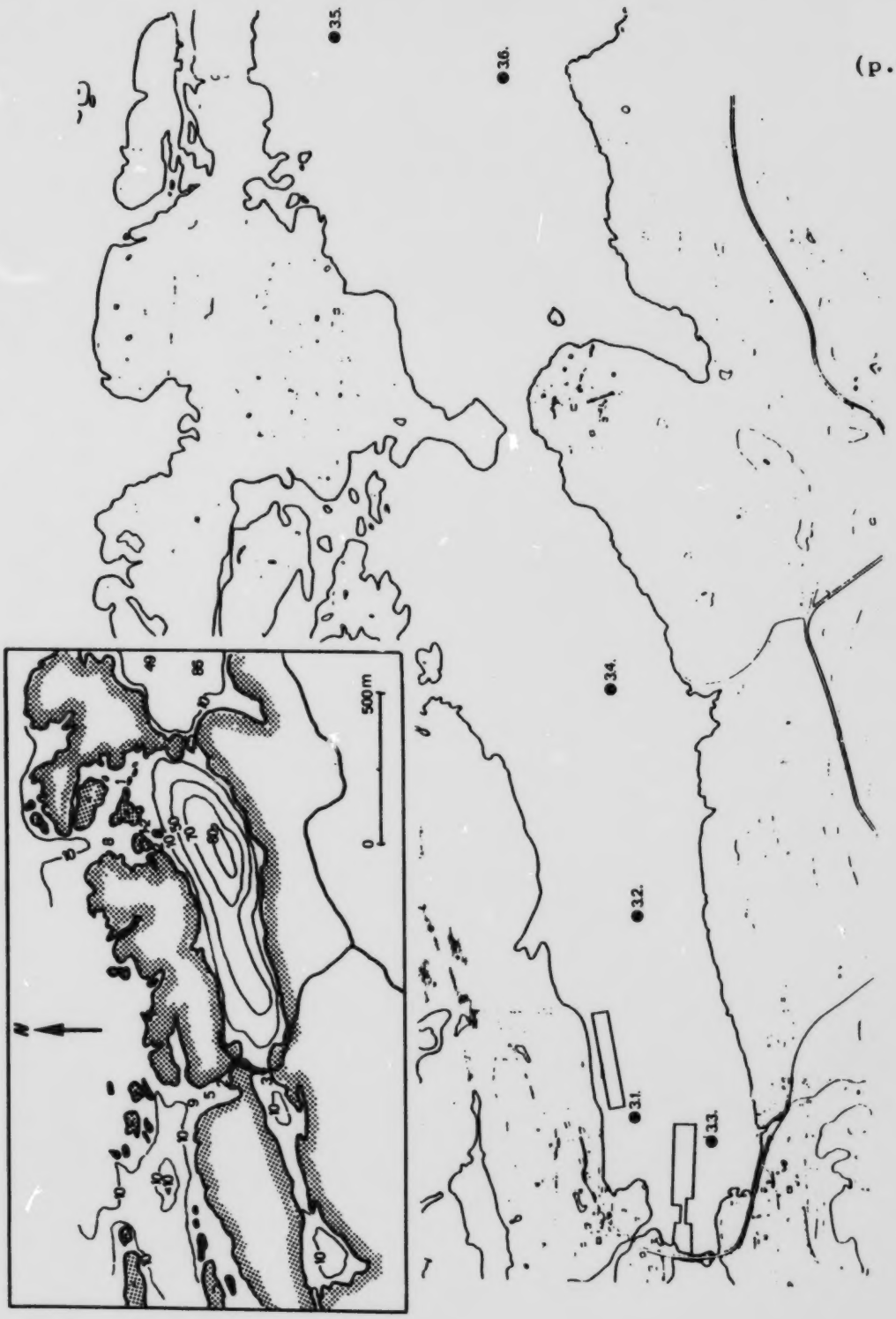

Fig. 3.3 Bunntopografi og lokalisering av anlegg og undersøkelsesstasjoner ved anlegg 3.

Bottom topography and location of benthos investigations at fish farm 3.

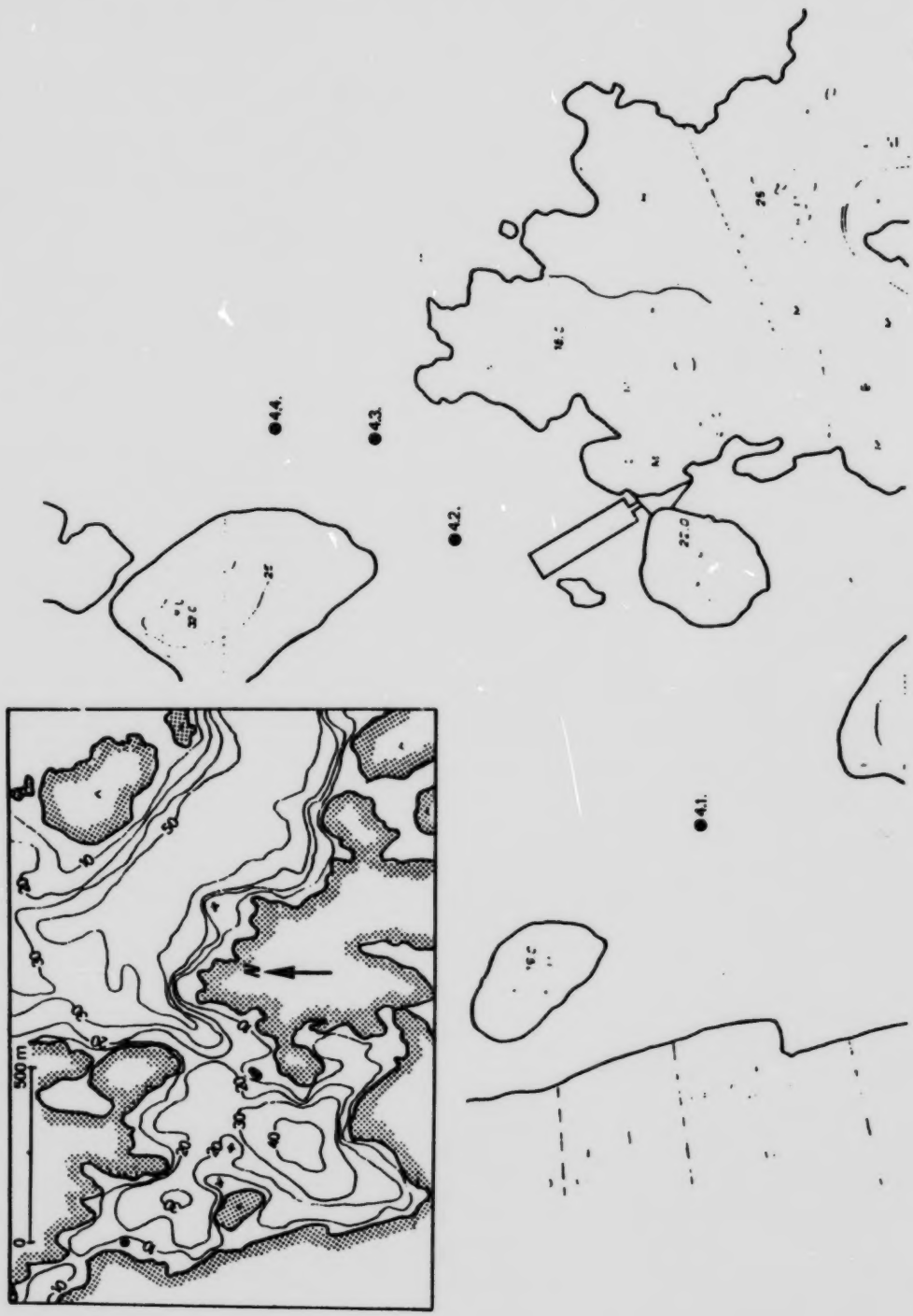

Fig. 3.4 Bunntopografi og lokalisering av anlegg og undersøkelsesstasjoner ved anlegg 4.

Bottom topography and location of benthos investigations at fish farm 4.

(p.8)

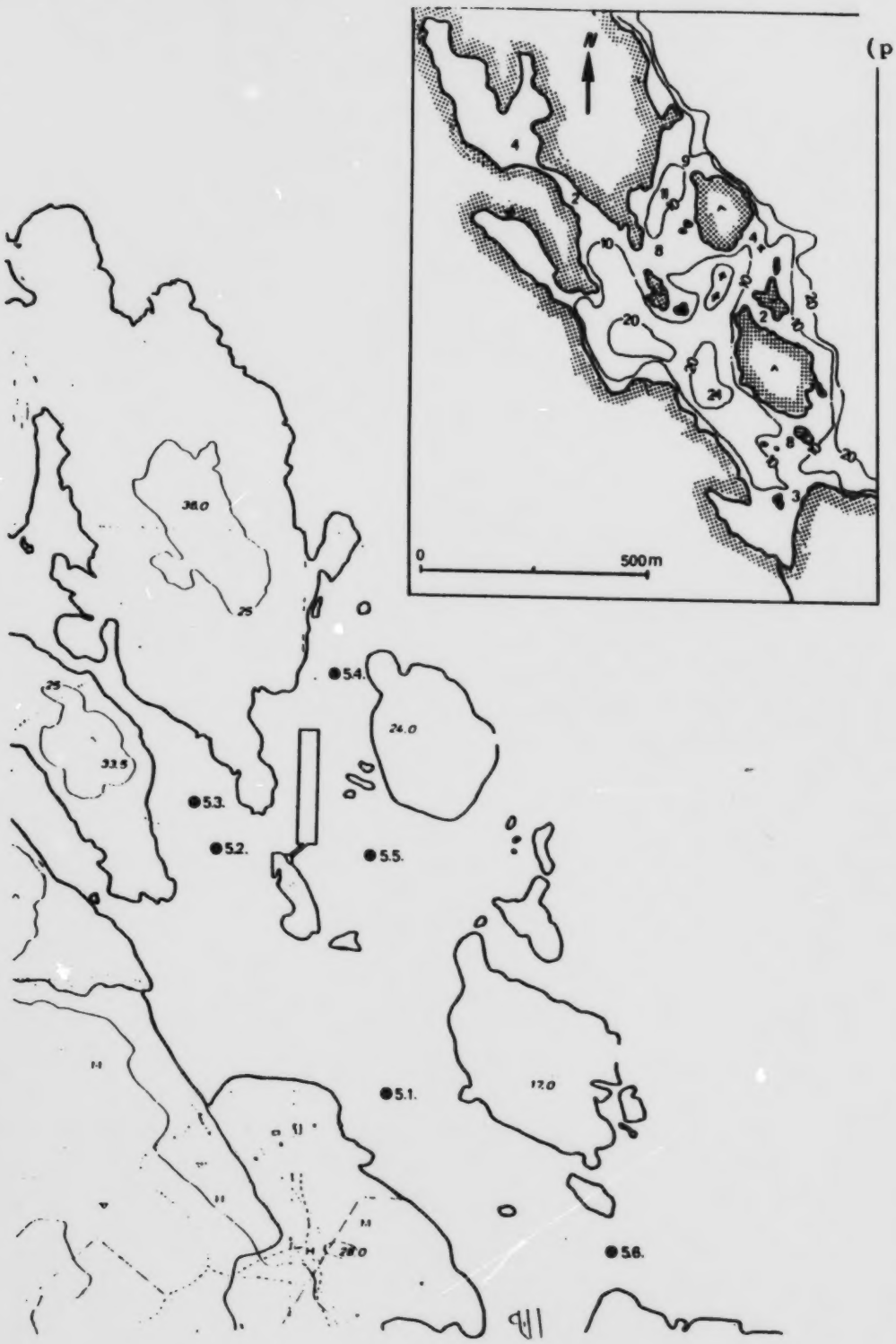

Fig. 3.5 Bunntopografi og lokalisering av anlegg og undersøkelsesstasjoner ved anlegg 5.

Bottom topography and location of benthos investigations at fish farm 5.

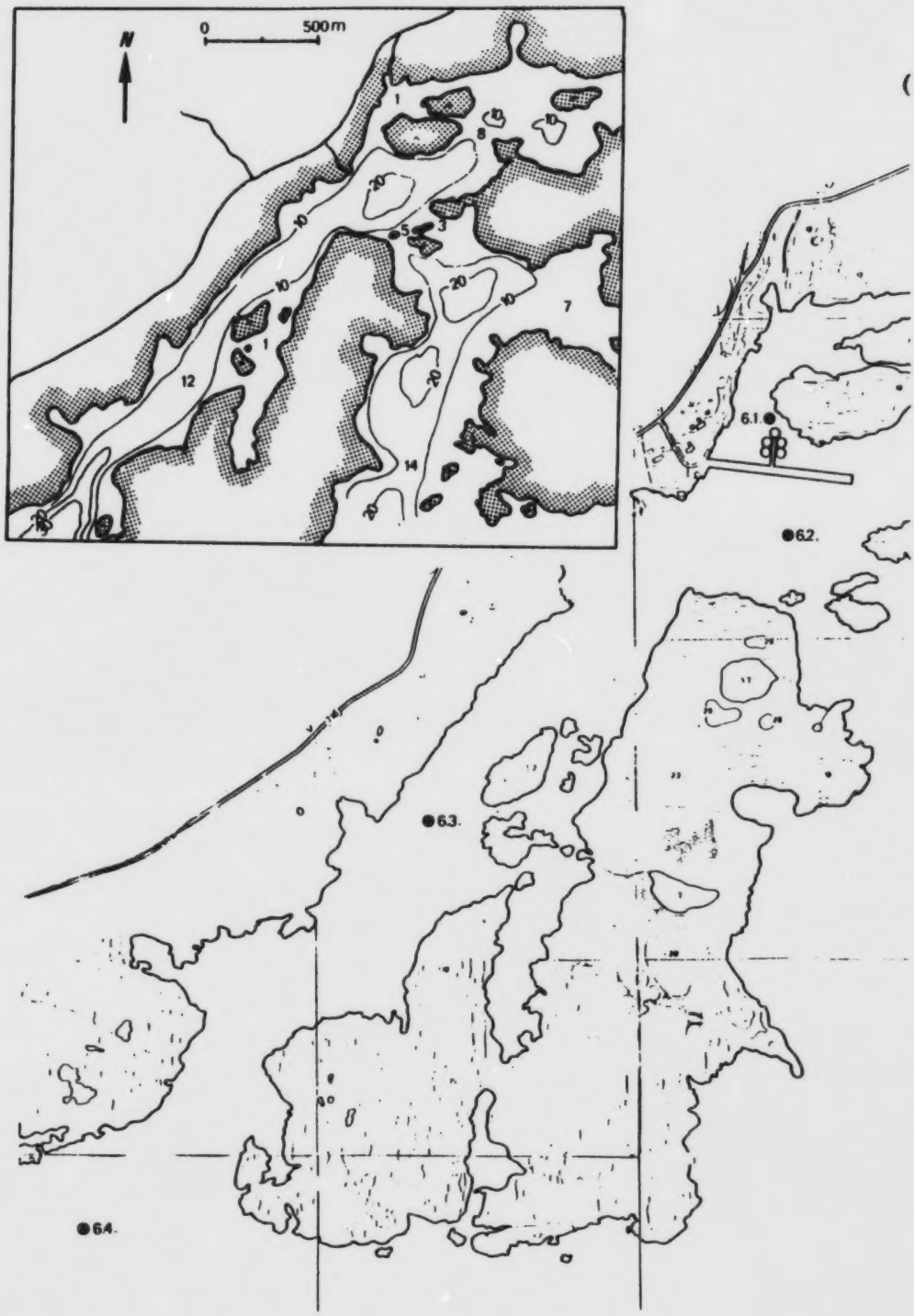

Fig. 3.6 Bunntopografi og lokalisering av anlegg og undersøkelsesstasjoner ved anlegg 6.

Bottom topography and location of benthos investigations at fish farm 6.

(p.10)

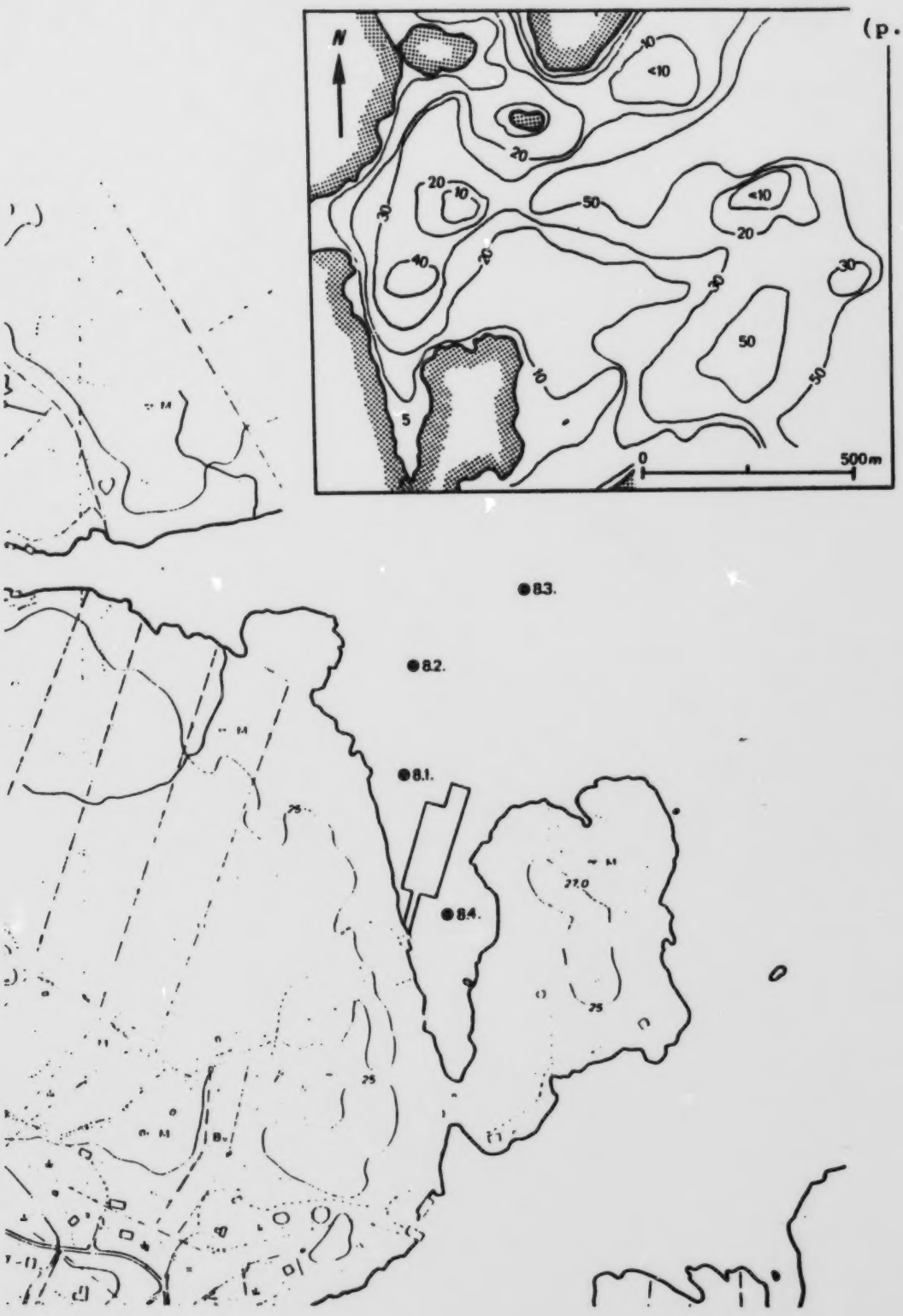

Fig. 3.7 Bunntopografi og lokalisering av anlegg og undersøkelsesstasjoner ved anlegg 8.

Bottom topography and location of benthos investigations at fish farm 8.

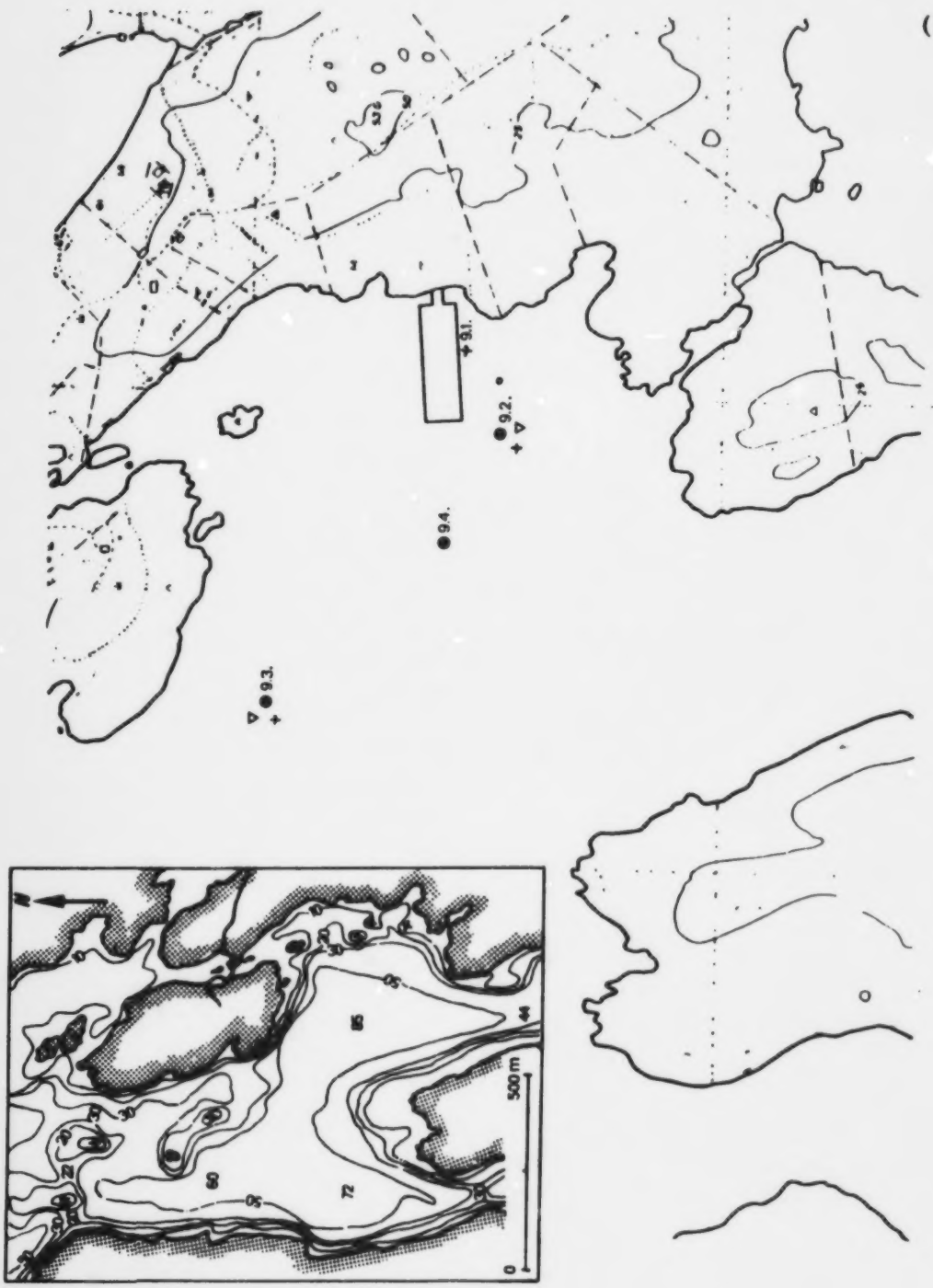

Fig. 3.8 Bunntopografi og lokalisering av anlegg og undersøkelsesstasjoner ved anlegg 9. + - angir næringssaltundersøkelser, ▽ - angir sedimenteringsundersøkelser, ● - angir bunndyrundersøkelser.

Bottom topography and location of benthos investigations at fish farm 9. +, ▽, and ●, represent sampling stations for nutrients, sedimentation, and benthos investigations respectively.

3.2. Hydrography and currents (p.12)

All the areas studied are localized in areas close to the coast and the hydrographic conditions are characteristic for these areas.

Salinity

Tabell 3.1. Årsmiddel, maksimum- og minimumsaltholdighet i 2,5 m dyp ved undersøkte anlegg i 1983-84. For definisjon av hydrografiske soner, se tekst.

Annual mean, maximum and minimum salinity at 2.5 m depth for all fish farms investigated during 1983-84. For definition of hydrographic zones see text.

Anlegg nr.	1	2	3	4	5	6	7	8	9
Årsmiddel. salt-holdighet (‰)	33.1	30.7	32.9	30.1	30.1	33.1	33.1	30.6	30.8
Maksimum salt-holdighet (‰)	34.4	32.9	34.1	32.9	32.9	34.3	34.4	32.7	32.8
Minimum salt-holdighet (‰)	30.0	27.7	31.2	25.9	25.9	31.1	30.9	26.5	27.1
* Hydrografiske soner	A	B	A	B	B	A	A	B	B

* A = Kystsone B = Overgangssone

* A= Coastal zone B= transitional zone

Table 3.1 shows that the annual mean for salinity was over 30 $^{0}/_{00}$ at all localities. The observed salinities for all the farms overall, fluctuated throughout the year between 26 $^{0}/_{00}$ and

34 ‰ with the highest values observed in the winter months.

Farms nos. 1, 3, 6 and 7 are located in the Coastal Zone where the salinity throughout the year is higher than 30 - 31 ‰ and the temperature conditions to a lesser degree is affected by local meteorological conditions. During the year there are also small differences in temperature and salinity with the depth, and the yearly and short period variations are lower than in the transition zone.

Farms nos. 2, 4, 5, 8 and 9 are located in the (p.13) transition zone where the water masses are a mixture of coastal and fjord water. This means that the lowest salinity in the summer months falls between 25 ‰ and 30 ‰. In periods there is a more definite layering and there are also higher short terms variations in temperature and salinity than in the coastal zone.

Temperatur

Tabell 3.2. Årsmiddel, maksimum- og minimumtemperaturer i 2,5 m dyp ved de undersøkte anlegg i 1983-84. - angir at datagrunnlaget ikke var tilstrekkelig til å beregne årsmiddel.

Annual mean, maximum and minimum temperatures at 2.5 m depth for all fish farms investigated during 1983-84. - indicate insufficient data for calculating yearly average.

Anlegg nr.	1	2	3	4	5	6	7	8	9
Årsmiddel. temperatur (°C)	-	8.9	-	9.3	9.3	-	-	9.0	8.9
Maksimums-temperatur (°C)	13.5	13.7	13.3	14.7	14.7	12.5	13.5	14.5	14.0
Minimums-temperatur (°C)	3.7	2.7	3.6	2.7	2.7	3.5	3.7	2.7	2.7

The annual mean was about 9° C (Table 3.2). The minimum temperatures were, however, ca 1° C lower at farms nos. 2, 4, 5, 8 and 9 than at farms 1, 3, 6 and 7. The maximum temperatures fluctuated between 12.5° C and 14.7° C. It was therefore no essential differences in the temperature environment in the installations studied in 1983 - 1984.

Oksygeninnhold

Tabell 3.3. Midlere, maksimum og minimum oksygeninnhold i 2,5 m og nær bunnen i de undersøkte anlegg i 1983-84.

Average, maximum and minimum oxygen concentrations at 2.5 m depth and near the bottom at all fish farms investigated during 1983-84.

Anlegg nr.	1		2		3		4		5	
Dyp (m)	2.5	11.0	2.5	13.0	2.5	20.0	2.5	11.0	2.5	10.0
Midlere oksygen-innhold (ml/l)	6.5	6.6	6.8	6.2	6.4	6.6	6.8	6.6	6.9	6.9
Maksimum oksygen-innhold (ml/l)	7.9	8.0	8.7	7.8	7.9	7.9	8.7	8.6	8.8	8.8
Minimum oksygen-innhold (ml/l)	5.6	5.7	5.5	4.9	5.4	4.5	5.8	5.4	5.5	5.3

Anlegg nr.	6		7		8		9	
Dyp (m)	2.5	12.0	2.5	8.0	2.5	13.0	2.5	9.0
Midlere oksygen-innhold (ml/l)	6.6	6.5	6.9	6.7	6.7	6.2	6.7	6.8
Maksimum oksygen-innhold (ml/l)	7.8	7.6	8.0	7.3	8.9	8.9	8.9	8.7
Minimum oksygen-innhold (ml/l)	5.6	5.1	6.3	6.2	5.4	4.3	5.8	5.3

Table 3.3 shows that the highest and lowest observed values of the oxygen content in the farms studied were respectively 8.9 ml/l and 4.3 ml/l. Mean oxygen contents in 1983 - 1984 varied at 2.5 m depth between 6.4 and 6.9 ml/l and close to the bottom between 6.2 and 6.9 ml/l. Mean oxygen contents at 2.5 m and 10 m depths at the farms were up to 10% lower than at the reference (control) stations in unpolluted areas. The maximum values at 2.5 and 10 m depths were 3% higher and 8% lower than at the reference station. There were occurrences of relatively low oxygen values close to the bottom on occasions. At farm 8 at 10 m depth there were , for example, registered 30% lower oxygen values than at the reference station. As described under 3.1.1. farms nos. 3 and 9 are located inside sills (Figs. 3.3 and 3.8). The sill (p.15) depth to the basin at farm 9 is 30 m and the greatest depth inside the sill is about 80 m. The oxygen development at 50 m depth is chosen to represent the oxygen conditions in the basin waters in 1983 - 1984 (Fig. 3.9). In the falls of 1983 and 1984 there were several period without inflow of water to the basin. This resulted in a critically low oxygen content in December 1983 (1.5 ml/l) and near critical conditions in December 1984(2.4 ml/l). The oxygen consumption in the fall of 1983 (Sept.-Dec.) was about 1.2 ml/l per month and in the fall of 1984 about 0.8 ml/l per month (Oct.-Dec.).

The basin where Farm no. 3 is located has a water depth at the sill of 4-5 m with the greatest depth inside the sill ca 80 m (Fig. 3.3). In 1983 - 1984 the lowest observed oxygen value at 20 m depth was 4.5 ml/l (Table 3.3). In Fig. 3.10 it can be seen that there was a reduction in the oxygen content in the bottom water under 30 m depth from January to December 1984. Below 50 m the oxygen consumption was considerably higher than between 30 and 50 m. In December the oxygen content below 60 m was critically low (0-1 ml/l, while for comparison it was 4.3 ml/l at 50 m depth. The oxygen consumption below 50 m depth from July to December was ca 0.8 ml/l per month and in 40-50 m depth 0.2 ml/l per month. Especially in the upper 30 m of the water column there seems to be a sufficient supply of oxygen in spite of the shallow sill at the mouth of the basin.

(p.16)

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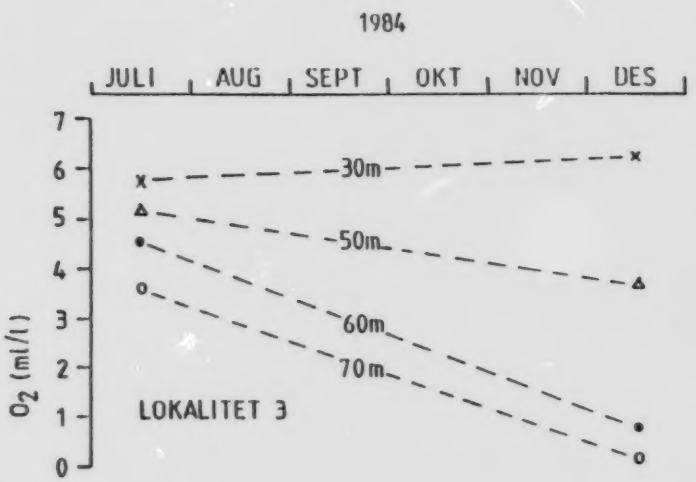

Fig. 3.10. Oksygenutviklingen i 30 m, 50 m, 60 m og 70 m dyp ved anlegg 3 i 1984.

Changes in oxygen concentrations at 30, 40, 50, 60 and 70 m depth at fish farm 3 in 1984.

Currents

The currents in the installations were observed 1-4 m under the cages (Table 3.4). At farms 3, 6 and 7 the mean current velocity was under 2 cm/s, and there were long periods with no currents (40 - 70%). The highest observed current velocity at these farms was ca 5 cm/s. The rest of the farms (1, 2, 4 and 5) had mean current velocities between 2 and 3.0 cm/s. Farm 1 had the highest currents where ca 10% of the current observations were above 7.5 cm/s.

The current measurements show that there were relatively weak currents at most of the installations, but the conditions are probably representative for farms in sheltered localities.

(p.17)

Tabell 3.4. Strømforholdene ved anlegg 1-7.

Current regime at fish farms 1 to 7.

Anlegg nr. Farm no.	1	2	3	4	5	6	7
Måledyp (m) Measuring depth	5	9	8	6	6	6	5
Midlere strømfart (cm/s) Mean current veloc.	2.5	2.1	1.5	2.7	2.0	1.5	1.5
Strømstille (%) No current	42	-	57	-	2	70	41
% obs.less than % observasjoner mindre enn 2.5 cm/s	75	75	91	70	70	96	85
% obs. less than % observasjoner mindre enn 5 cm/s	83	92	100	82	99	100	97
% observasjoner mindre enn 7.5 cm/s	89	98	-	90	100	-	98
Main current dir. Hovedstrømsretninger Current against dir. (strøm mot retning)	VNV ØNØ	NV SSV	NV ØSØ	SSV NØ	NNV SSØ	VNV ØSØ	VNV ØSØ

3.3. Operational data and sedimentation conditions under the farms. Other stresses on the recipients

The information is presented in Table 3.5 and in Fig. 3.11 that show monthly feed usage at farms 2 and 9. It can be seen from the table that the farms have been in operation from 4 to 13 years. Problems with self contamination occur usually after 3 years. All the farms have been in operation longer than this. The volumes permitted according to the licences varies from 5000 to 16,000 m^3, and the volumes of fish produced per year from 65 to 230 tonnes. Most of the Norwegian food fish installations fall within these limits. Farm 4 differs from the others in having a low production relative to the licensed cage volume.This is due to the fact that this is a research installation and is not primarily involved in commercial production. The feed factor (dry weight feed/wet weight fish) was around 1.5. Both wet feed (70 % water content), moist feed (40 % water content) and dry feed (10 % water) are being used.

The thickness of organic waste under the (p.18) installations varied from 0 - 40 cm. There were also large differences in the degree of decomposition of the waste. Under the farms that had the least amount of organic waste, live benthic animals were observed.

Other loads on the recipient came chiefly from other fish farms. This is the case for Farms 1 and 7 that were located in the same area, and for Farm 6 that was located near another farm. Farm 9 differs by being in a recipient with a total of 7 farms with a total yearly production of about 400 tonnes. In addition there were also some sewage outlets and a fish processing plant in the area.

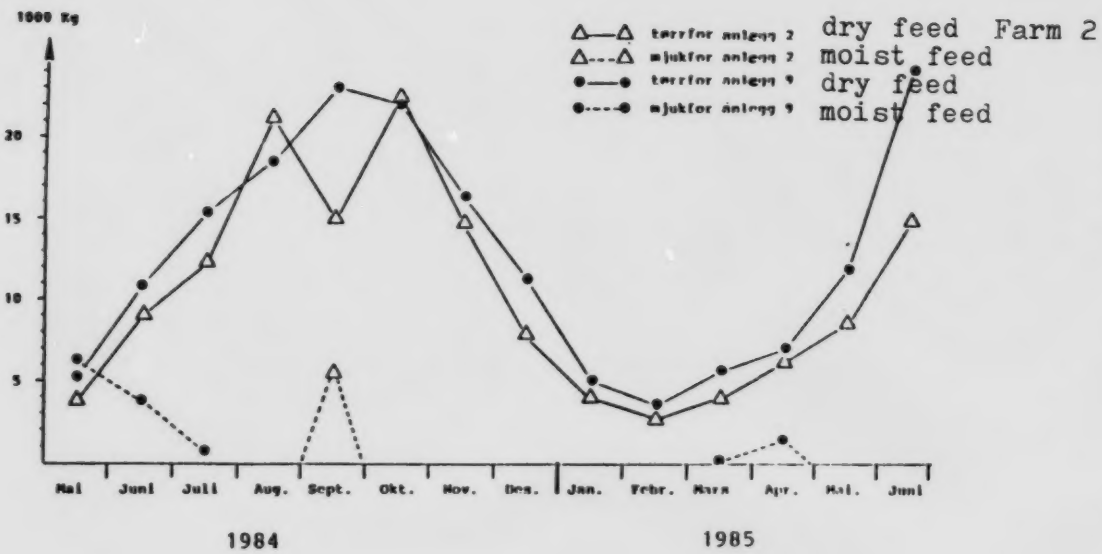

Fig. 3.11. Forbruk av fôr og fôrtype ved anlegg 2 og 9 i perioden mai 1984 - juni 1985.

Food usage and type at fish farm 2 and 9 during the period May 1984 to June 1985.

Tabell 3.5. Konsesjonsvolum for undersøkte anlegg i ulike perioder, tidspunkt for innsamling av bunndyrprøver, driftsdata siste år før innsamling, anleggstype, beskrivelse av forholdene under anleggene. Tabellen gir også opplysning om organisk belastning på resipient.

VF = våtfôr, MF = mjukfôr, TF = tørrfôr, M = mudder, FS = fin sand, GS = grov sand, F = fast fjell.

Concession volumes during different periods for the fish farms investigated, collection time of benthic fauna, production data for the year prior to the investigation, farm type, description of bottom conditions under the farms and degree of organic loading.

VF = wet fooder, MF = soft fooder, TF = dry fooder, M = mud, FS GS = coarse sand, F = rock bottom.

Farm No.	Size of farm Time period	Volume	Study period	Fish prod (t)	Feed quant. (t)/type	Anleggstype	Conditions under the farms: Original sediment	Organic waste(cm)/ degree of decomp.	Macrofauna	Other organic loading on recipient
Anlegg 1	1973-76 1976-84	3 000 8 000	05.1984	80	250 MF	Frittliggende merder	FS/GS	Mye møller.	Yes Ja	Farm 7 located in same area.Insignif. farming.Scattered habitation.
Anlegg 2	1980-84	5 000	05.1984	75	160 TF	Kompaktanlegg/landpreg Freefloating cages	FS/F	15-45 Lite møller. Little decomp.	No Mel	ca 100 people in area Insignificant, no farming of permanent habitation.Few cottages.
Anlegg 3	1973-78 1978-80 1980-84	3 000 8 000 13 000	05.1984	120	360 MF	Kompaktanlegg/landpreg Compact/landfast	FS/GS	0-2 Mye møller. Much decomp.	Ja	Little, no farming.8-9 houses
Anlegg 4	1978 1983-84 1984-85	3 500 5 500 10 800	05.1985	25	7.6 VF 62.5 MF 2.4 TF	Kompaktanlegg/landpreg	FS/F	0-40 Delvis møller. Part decomp.	Ja	Little farming and sewage. Runoff from smolt prod.200,000 fish/y
Anlegg 5	1980-85	15 000	05.1985	230	360 MF 170 TF	Kompaktanlegg/landpreg	FS/GS/F	15-30 Lite møller.	Mel	Insignificant, no farming or permanent habitation
Anlegg 6	1978-84 1984-85	3 000 8 000	06.1985	70	120 MF 55 TF	Kompaktanlegg/landpreg	M/FS	0-10 Mye møller.	Ja	One other fish farm with prod. 75 t/y, no farming, 3 houses
Anlegg 7	1972-80 1980-84 1984-85	5 000 13 000 16 000	06.1985	110	660 VF	Frittliggende merder	FS	0-2 Mye møller.	Ja	As for Farm 1 Insignificant in cove where farm is.
Anlegg 8	1980-84 1984-85	5 000 7 000	05.1984	95	160 TF	Kompaktanlegg/landpreg	FS/GS	0-15 Lite møller.	Mel	In nearby cove(<500 m) effluent from slaughtering inst./industr. build. sewage from 200 people.
Anlegg 9	1979-80	5 000	1984	65	180 MF	Kompaktanlegg/landpreg	FS/GS	0-10 Lite/delvis møller. Little/part decomp.	Mel	Total 7 fish farms, tot. prod. 400 t. Scatt.popul.,little farming. Outside sill sewage outlet from 680 people, proc. water from fish proc. plant.

4. NUTRIENT SALTS (p.20)

4.1. Summary

The concentrations of nitrite , nitrate, orthophosphate and silicate were studied in and around two farms in the period October 1984- April 1985. Nitrate and silicate did not exhibit elevated values near the installations. These nutrient salts seem to be guided by natural biological and physical processes in the water masses. The concentration of orthophosphate was higher in areas close to the farms in some of the measurements. The values for orthophosphate were generally somewhat higher in the most enclosed area. Nitrite showed some elevated concentrations near the installation in two of the measurements.

4.2. Objectives

The objectives of the study were:

- to find out if there are elevated concentrations of nutrient salts around fish farms
- to study if these could be used to monitor marine recipients with fish farms. Nitrite formed through nitrification is in this connection especially interesting
- to accumulate basic data for use in the study of sedimentation and benthic fauna.

4.3. Materials and methods

4.3.1. Farms studied

Nutrient salts were studied at Farms 2 and 9. These were also studied with respect to sedimentation. See section 5.

Farm 2 is located in a small bay at the mouth of a fjord. It

is sheltered by small islets, and the currents in the farm are weak, outside the currents are good. The area topography, hydrography, currents and the location of the farms is described in more detail in sections 3.1 and 3.2.

The production in the installation was 75 tonnes fish in 1984, feed usage 160 tonnes. There are no other loadings of the recipient besides the fish farm. Further information on the farm is given in sect. 3.3.

Farm 9 is placed in a small sill fjord with water depth at the sill 30 m and depth in the basin 89 m. The area is relatively enclosed and currents weak. Topography, hydrography and currents are given in sections 3.1 and 3.2. The placement of the farm is also shown there (Fig. 3.8).

The farm produced 65 tonnes fish in 1984 and used 180 tonnes moist feed. Inside the sill there were several farms with a total production of over 400 tonnes. For further information on the installation and the recipient see sect. 3.3.

4.3.2. Collection program

Samples were taken at three stations at each farm. The collection points are shown in Figs. 3.2 and 3.8.

A total of 6 collections were made in the period from October to March in the winter of 1984/85. The dates, sample depths and depths to the bottom are given in Table 4.1. In addition, samples were taken in a grid around Farm 9 on February 12, 1985. The collection points are given in Appendix 1 and can also be found in the presentation of results (sect. 4.4.) The samples were taken at 0 and 2.5 m depths. Current measurements were also taken in the recording period.

Table 4.1.

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Tabell 4.1. Dato for innsamling av næringssaltprøver (A), prøvedyp og totaldyp (B).

Date over nutrients sampling (A), sampling depth and total depth (B).

A				29.10.84.		16.01.85.	
				12.12.84.		12.02.85.	
						13.03.85.	
						10.04.85.	
B	St.nr.		2.1	2.2	2.3	9.1	9.2	9.3
Sample depth	Prøve dyp (m)		0	0	0	0	0	0
			2.5	2.5	2.5	2.5	2.5	2.5
			7	7	7	7	7	7
			10	10	10	10	10	10
			15	15	15	15	15	15
			-	20	20	20	20	20
			-	-	-	-	25	-
			-	-	-	-	-	30
			-	-	-	-	-	40
			-	-	-	-	-	60
			-	-	-	-	-	80
Bottom depth	Bunndyp(m)		16	23	33	23	30	89

4.3.3. Analyses

The water samples were preserved with chloroform and kept cool (HAGEBØ and RAY 1984). The analyses included nitrite (NO_2^-), nitrate (NO_3^-), orthophosphate (PO_4^{3-}) and silicate (SiO_2). They were performed at the Directorate of Fisheries Institute of Marine Research according to standard methods (FØYN, MAGNUSSEN and SEGLEM 1981). Current velocity and -direction was measured with SD-1000 current meter.

4.4. Results

All the results from the nutrient salt investigations are presented in Appendix 1.

4.4.1. Orthophosphate

Figures 4.1 and 4.2 show the concentration of orthophosphate in the water masses around Farms 2 and 9 in the period October 1984 - April 1985. The values below sill depth at station 9.3 are not included in the figure.

Fig. 4.1.

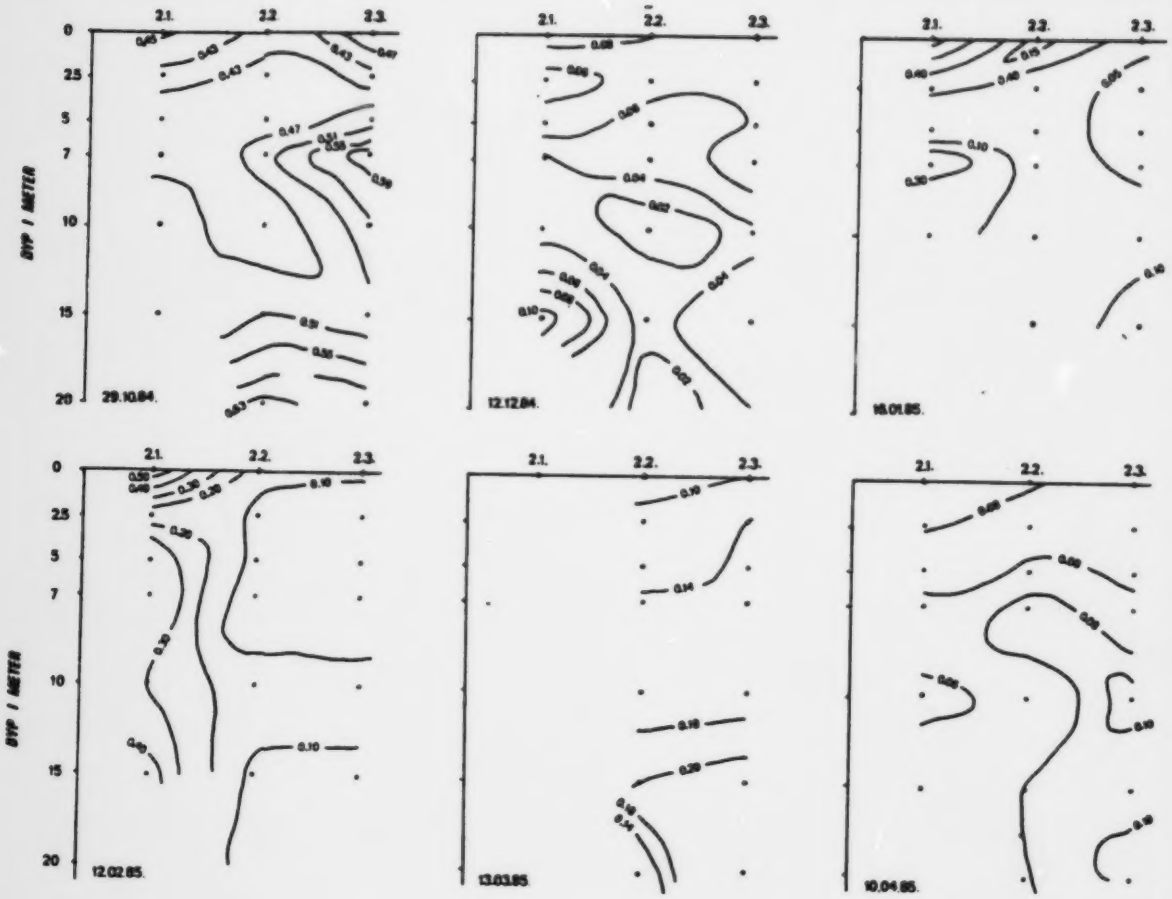


Fig. 4.1. Konsentrasjon av ortofosfat ved anlegg 2 i perioden oktober 1984 til april 1985. Konsentrasjonene er angitt i µM. Stasjon 2.1 ligger kloss i anlegget, stasjon 2.3 lengst borte. Innsamlingssted vist i Fig. 3.2.

Orthophosphate concentrations during the period October 1984 - April 1985 at fish farm 2. Concentrations in µM. Station 2.1 is located in direct proximity of the farm, and station 2.3 farthest from it. Sampling location shown in Fig. 3.2.

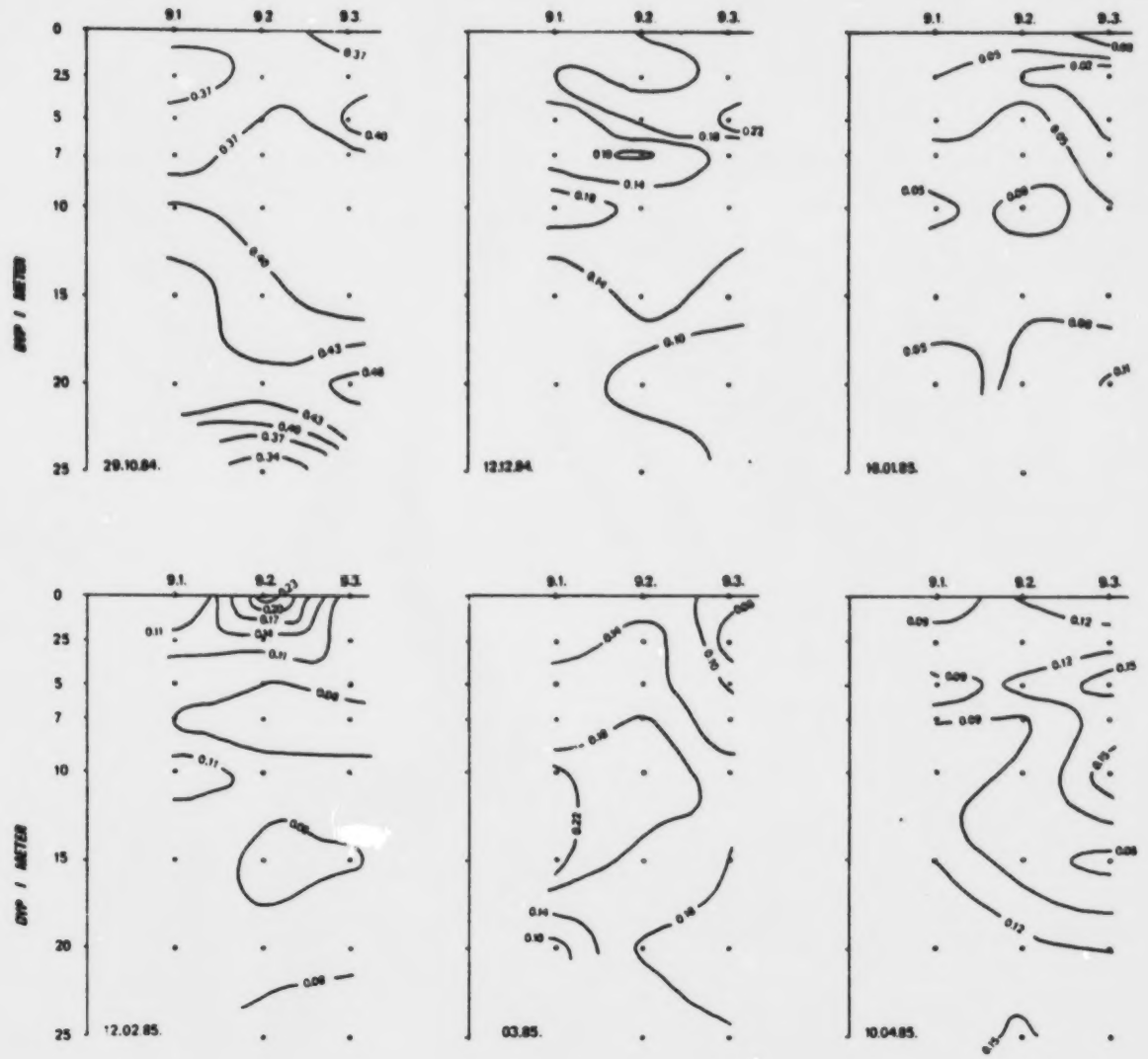


Fig. 4.2. Konsentrasjon av ortofosfat ved anlegg 9 i perioden oktober 1984 til april 1985. Konsentrasjonene er angitt i µM. Stasjon 9.1 ligger like ved anlegget, stasjon 9.3 lengst borte. Verdier under terskelnivå på st. 9.3 er ikke tatt med på figuren. Innsamlingssted vist på Fig. 3.8.

Orthophosphate concentrations during the period October 1984 - April 1985 at fish farm 9. Concentrations in µM. Station 9.1 is located at the periphery of the farm, and station 9.3 farthest from it. Measurements below sill depth are not shown for station 9.3. Sampling location shown in Fig. 3.8.

The concentration of orthophosphate in the surface water around Farm 9 on February 12th, 1985 is shown in Fig. 4.3. The figure also shows the current in the study period between 11:15 (a.m.) and 13:10 (p.m.).

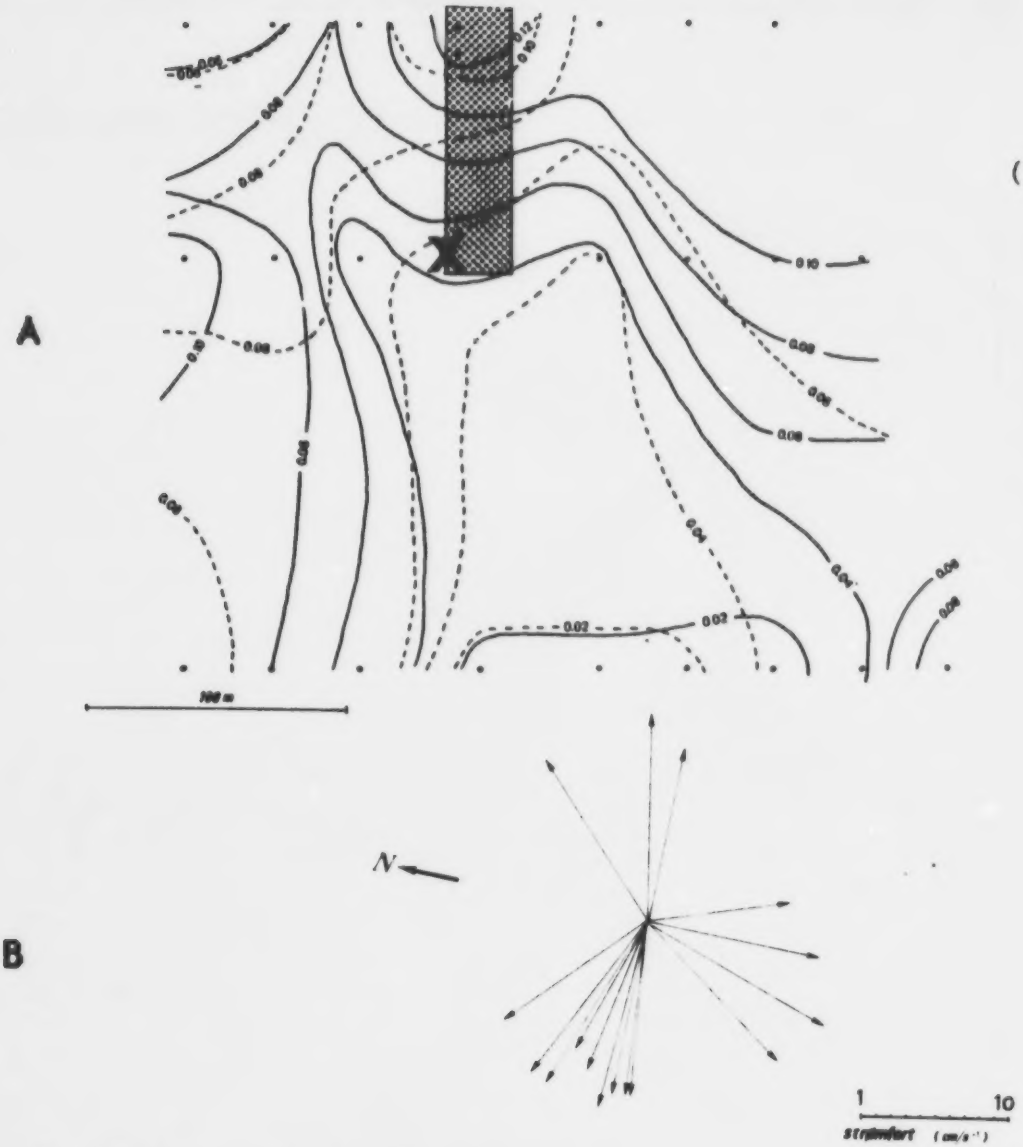


Fig 4.3. Konsentrasjon av ortofosfat og strøm i overflatevannet ved anlegg 9 den 12. februar 1985. Skravert felt angir anlegget. X angir strømmålerens plassering. Se oversiktskart Fig. 3.8.

A. Horisontalfordeling av ortofosfat. Verdiene er angitt i µM. Striplet linje angir verdiene på 0 m, heltrukken på 2,5 m dyp.
B. Strøm i undersøkelsesperioden kl. 1115-1310.

Orthophosphate concentrations and current in surface water at fish farm 9 (12.02.85). Striped area shows the fish farm. See Fig. 3.8 for a more general map. X illustrates the position of the current meter.

A. Horizontal distribution of orthophosphate. Concentrations in µM. Dashed lines represent the values at 0 m depth, solid lines at 2.5 m depth.
B. Currents during the period of investigation (11:15 - 13:10 Hour)

The concentration of orthophosphate is highest in December - January and falls towards april. The values are in general somewhat higher in the enclosed area near Farm 9 than the values near Farm 2. (p.26)

The concentrations in the upper water layers follow the usual seasonal pattern and are in the area 0.1 - 0.7 uM. This is normal for the area (ERGA 1980, REISEGG 1982). The sharply higher values (higher than 1.75 µM, see Appendix 1) below sill depths on station 9.3 are due to poor water exchange in the basin.

The results fluctuated markedly from station to station for the same collection. For some of the measurements the values close to the farms were higher than further out in the recipient. However, there still does not appear to be a clear tendency to elevated concentrations in the zone near the farms. Detailed investigations near farm 9 show that the concentrations at 2.5 m depth in the farm were higher than in the area immediately around it.

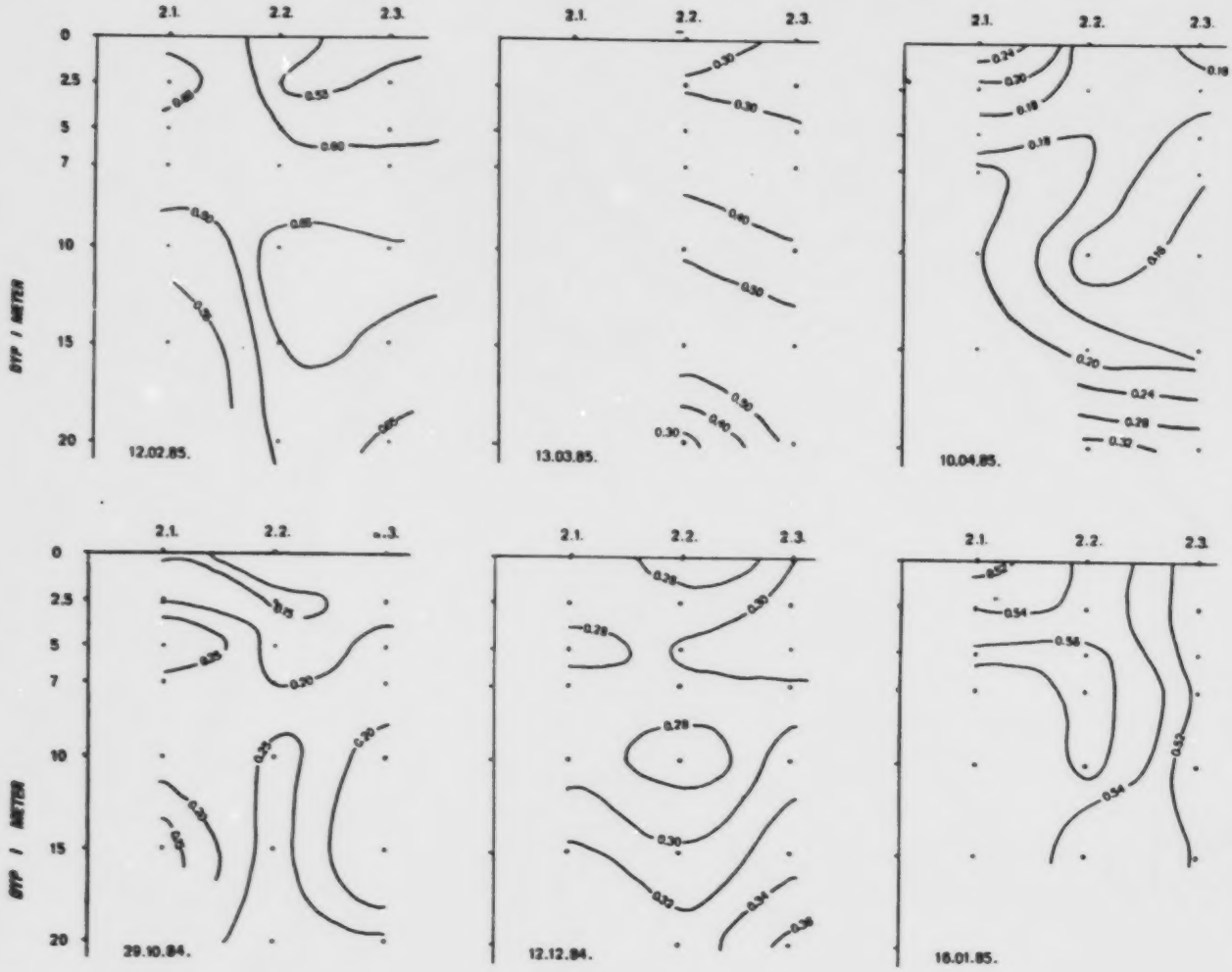
4.4.2. Nitrite

The results of the nitrite investigations are presented in Figs. 4.4, 4.5 and 4.6. The measurements taken on January 16th and February 12th show elevated levels at Farm 2. There is no basis to conclude from the other measurements that there are higher concentrations in the zone near the farms than further out in the recipient. This also applies to the detailed investigation at Farm 9.

4.4.3. Nitrate and silicate

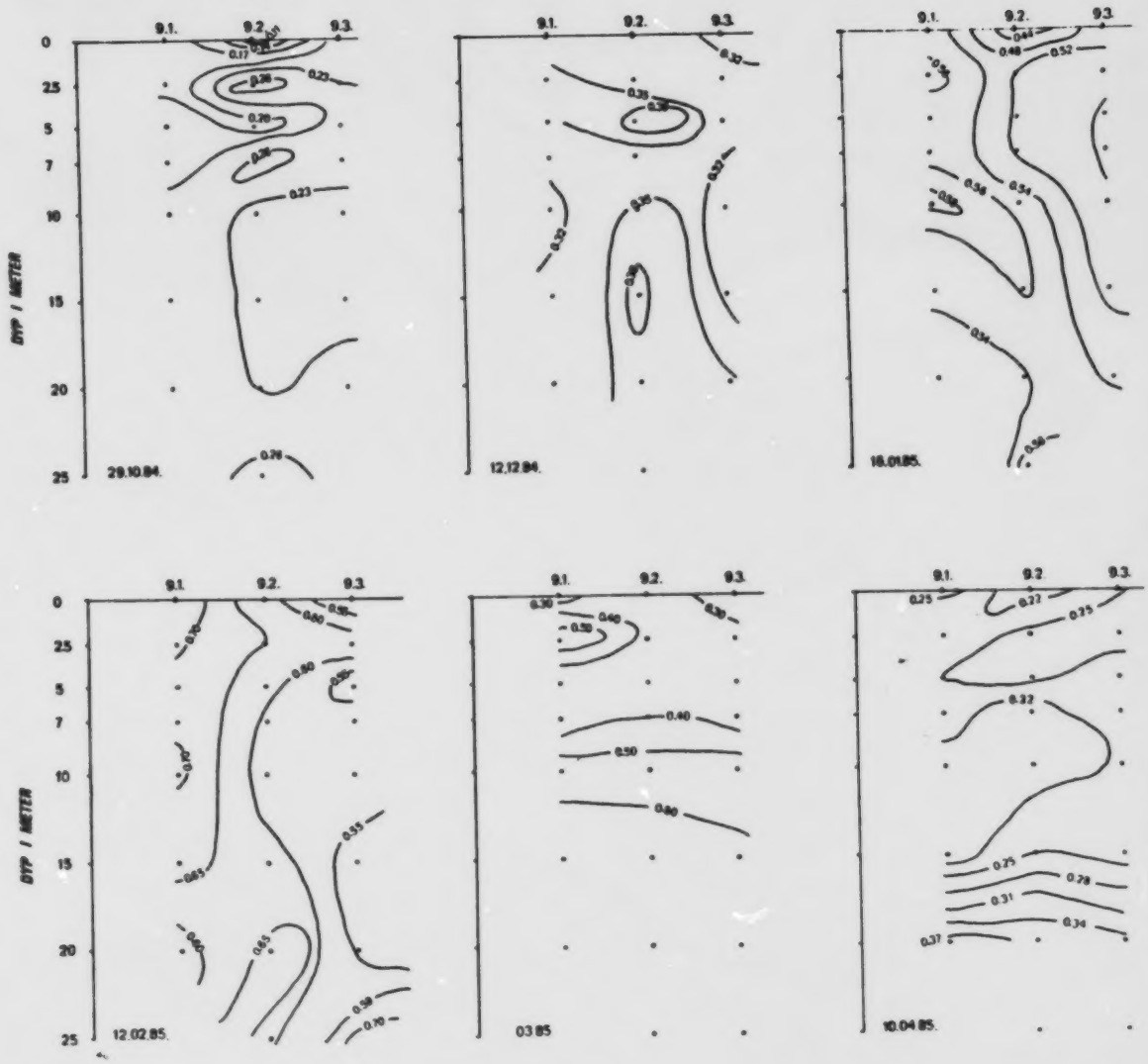
The concentrations of nitrate and silicate show the usual seasonal variations (see Appendix 1). The values increase towards a winter maximum of respectively 9 and 5.7 um and then fall towards zero during the spring bloom. For both nutrient salts the concentrations at Farm 9 were somewhat higher than at Farm 2. The

water below sill depth at station 9.3 has sharply higher values. This is due to stagnant basin water. Neither nitrate nor silicate exhibited elevated concentrations near the farms.



Figur 4.4. Nitrittkonsentrasjonen ved anlegg 2 i perioden oktober 1984 - april 1985. Konsentrasjonene er angitt i µM. Stasjon 2.1 ligger like ved anlegget, st. 2.3 lengst borte. Innsamlingssted er angitt på Fig. 3.2.

Nitrite concentrations during the period October 1984 - April 1985 at fish farm 2. Concentrations in µM. Station 2.1 is located in direct proximity of the farm, and station 2.3 farthest from it. Sampling location shown in Fig. 3.2.

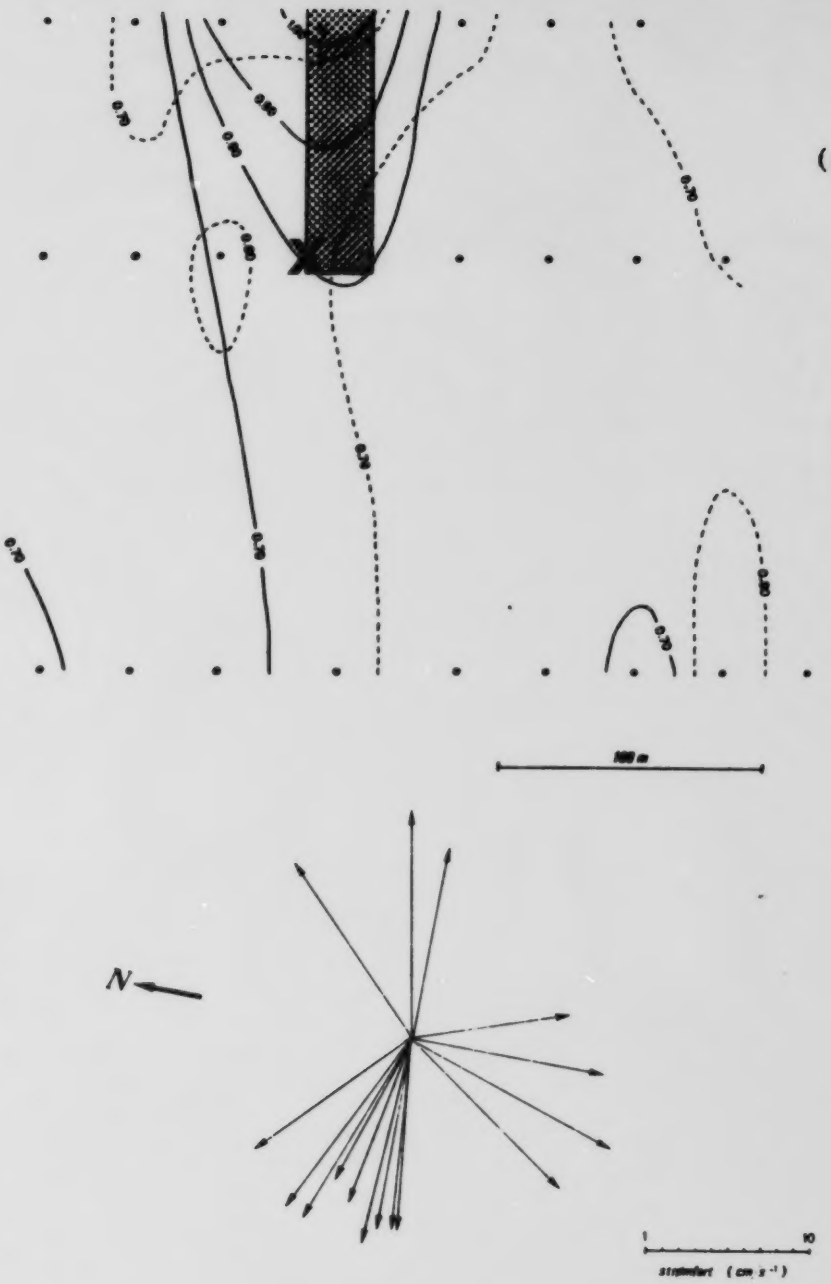


Figur 4.5. Nitrittkonsentrasjonen ved anlegg 9 i perioden oktober 1984 - april 1985. Konsentrasjonene er angitt i µM. Stasjon 9.1 ligger kloss i anlegget, st. 9.3 lengst borte. Innsamlingssted anvist på Fig. 3.8.

Verdiene under terskeldyp på st. 9.3 er ikke tatt med i figuren.

Nitrite concentrations during the period October 1984 - April 1985 at fish farm 9. Concentrations in µM. Station 9.1 is located in direct proximity of the farm, and station 2.3 farthest from it. Sampling location shown in Fig. 3.2.

Measurements below sill depth are not shown for station 9.3.



Figur 4.6. Nitrittkonsentrasjon og strøm i overflatevannet ved anlegg 9 den 12. februar. Skravert felt angir anlegg. X angir strømmålerens plassering. Se oversiktskart Fig. 3.8.

A. Horisontalfordeling av nitritt. Verdiene er angitt i µM. Striplet linje angir verdiene på 0 m, heltrukken på 2.5 m dyp.

B. Strøm i undersøkelsesperioden kl. 1115 - 1310.

Nitrite concentrations and current in surface water at fish farm 9 (12.02.85). Striped area shows the fish farm. See Fig. 3.8 for a more general map. X illustrates the position of the current meter.

A. Horizontal distribution of orthophosphate. Concentrations in µM. Dashed lines represent the values at 0 m depth, solid lines at 2.5 m depth.

B. Currents during the period of investigation (11:15 - 13:10 H.).

4.5. Discussion (p.30)

The concentrations of nutrient salts in the area are very low in the growth period of algae, and the primary production is limited due to lack of nutrients (ERGA 1980, REISEGG 1982). The amount of nutrient salts is in this period chiefly determined by the primary producers, and even very large releases are difficult to detect further out in the recipient (JOHANNESSEN 1985). In the winter period the concentration of nutrient salts is to a higher degree affected by supply. The investigations were therefore done in the period October - April.

The fish feed contains more phosphorus than the fish can utilize, and in addition there is the phosphorus in the waste feed (ÅSGÅRD, STORBAKKEN and AUSTRENG 1986). Fish farming therefore supplies phosphorus to the recipient. Danish studies have shown that the average feed factor there is 1.65 (dry weight feed/wet weight fish), and that the production of a tonne rainbow trout in a marine environment results in a release of 12 kg phosphorus (MØller 1987). Norwegian fish farmers use considerable quantities of moist feed that they produce themselves and it is therefore difficult to estimate exact values for nutrient release. The Norwegian Pollution Control Board has estimated that each tonne of fish produced will supply 20 kg phosphorus to the recipient; a value that seems reasonable based on what is known about the feed consumption.

Much of the phosphorus released is bound to particles in waste feed (ca 1% phosphorus) and in excrements (2% phosphorus, PENCZAK et al 1982). This waste often settles to the bottom under the farms, and these sediments release much phosphorus to the water above. HALL and HOLBY (1986) measured rates as high as 1-2 mmol phosphorus / m^2 d. This was 40 - 400 times higher than in the reference areas. Leakage from the sediment can give elevated phosphorus values in the water near the bottom under the farms (ERVIK, JOHANNESSEN and AURE 1985). In addition, there will be

phosphorus from the excretion products from the fish. The elevated values are, however, limited to the area of the farm itself and can not be detected further out in the recipient. Corresponding results have been found in Swedish (MÜLLER-HAECKEL 1986) and Scottish studies (GOWEN, personal communication).

The dynamics in the marine systems are without doubt the most important reason that phosphate gradients are not formed further out in the recipient. Even in localities with weak currents the water transport is so high that the releases are mixed with such large quantities of water that they are difficult to trace. Large supplies to enclosed areas can still give somewhat elevated concentrations as the case was at Farm 9 (see Sect.3 and 4.4.1).

Salmonids obtain a considerable part of their energy (p.31) by metabolizing protein. The metabolism produces large quantities of nitrogen-containing waste products that the fish excrete in the form of water soluble ammonia (NH_3) or urea (CO_2 $(NH_2)_2$). Studies show that as much as 68-88% of the nitrogen that the fish take in is excreted in this way, chiefly as ammonia GOWEN and BRADBURY, in press). In addition there are also considerable quantities of ammonium formed in the sediments (HALL and HOLBY 1986). In Norway the Norwegian Pollution Control Board (S.F.) has calculated that production of 1 tonne fish results in a release of 100 kilo nitrogen. This agrees very well with Danish values (MØLLER 1987). In the water the ammonia is protolyzed to ammonium (NH_4^+), and the large releases of ammonia results in sharply elevated ammonium concentrations in fish farms. ERVIK, JOHANNESSEN and AURE (1985) found that the values in the farms were 2-9 times higher than in unaffected reference areas. Ammonium is quickly taken up by primary producers. A more detailed report on this is in preparation (ERVIK, in.prep.). Ammonium is therefore not included in this study.

In seawater ammonia is nitrified through bacterial oxidation, i.e. converted to nitrate. In this process nitrite (NO_2^-) is an intermediate product. Another possible formation

method for nitrite is that plankton algae in poor condition leak nitrite. In primary producers nitrite is an intermediate product in the reduction of nitrate to ammonium. These conditions are further discussed by KIEFER et al. (1976) and HOLLIGAN, BALCH and YENTSCH (1984).

Due to the large production of ammonia, the nitrification is of special importance in connection with fish farming. High nitrification will result in elevated levels of nitrite and nitrate in and around the farms. Nitrite is of special interest since the concentration of this nutrient salt in natural systems is very low most of the year. Increased concentrations can be easily detected and be used to monitor releases from the farms. Elevated levels were only observed in two cases and in the farms themselves. The high concentrations in the month of October is a yearly occurring phenomenon and can probably be related to the fact that phytoplankton blooms release nitrite when they break down.

5. SEDIMENTATION

5.1 Summary

The sedimentation rates were not higher than those observed in other and unaffected areas. Sedimentation in the upper 25 m within a distance of 100-200 m from the farms was, however, higher than further out in the recipients. This was the case for total organic material, organic carbon, organic nitrogen and total particulate phosphorus. During the spring bloom, high chlorophyll values were measured in the immediate areas of the farms. The elevated sedimentation rates in the farms were in most cases found in the upper part of the water column in periods with high feed use. In a distance of about 250 m from the farms the sedimentation seemed to be little affected by the farms. The sedimentation was here lower than what is usual in such areas. No effect could be demonstrated near the bottom in a deep basin either.

In the area studied around the farms there was, however, a high C/N value in the sedimented material. This shows that the sedimented material was heavily decomposed. This can indicate that there was elevated biological activity in the areas around the fish farms. The increased sedimentation rates and high C/N values were most pronounced in an enclosed area where there was high aquacultural activity.

The studies therefore show relatively increased sedimentation rates in the immediate areas around the fish farms and that high C/N values in the organic material can be observed in a somewhat larger area around the farms. This is especially the case in periods of heavy feeding.

The sedimentation rate around the farms (100 m) was only 1/500 of those usually observed directly under fish farms. This means that by far most of the organic material from the installations settle to the bottom in the immediate area in localities with weak currents and moderate depths (10-20 m).

5.2. Objectives

The objectives of the study have been:

- to determine if operation of a fish farm leads to increased sedimentation from upper water layers at, and some distance from, the installation.

- to determine if increased sedimentation rates in the water column leads to an increased supply of material to the bottom.

- to study the sedimented material to evaluate if the biological activity in the area is affected by fish farming.

5.3. Abbreviations

Below is a summary of abbreviations used in the text.

KLO a equiv.	Chlorophyll a equivalents
POK	Particulate organic carbon
PON	Particulate organic nitrogen
TPM	Total particulate material
POM	Particulate organic material
PUM	Particulate inorganic material
TPF	Total particulate phosphorus
C/N	Relationship between number of carbon and nitrogen atoms

5.4. Materials and methods

5.4.1. Collection equipment

The collections were made with sediment collectors (traps) constructed from a model described by WASSMANN (1983). The equipment is presented in Fig. 5.1.

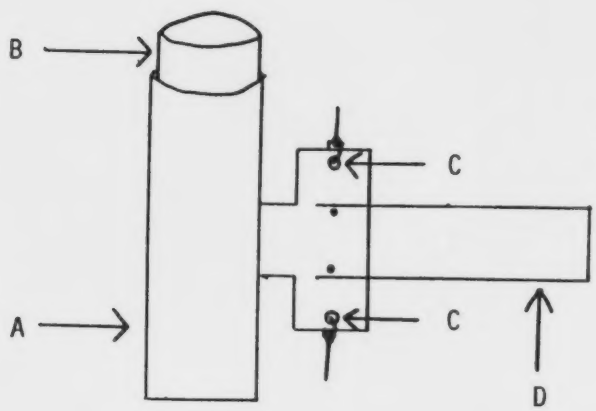


Fig. 5.1. Sedimentsamler. A - ytre rør av PVC, B - indre sedimentsamler av glass, C - festepunkt, D - ror.

Sediment trap. A - outer PVC container, B - inner glass cylinder, C - fixation points, D - rudder.

The sediment traps were fastened to a rig as shown in Fig. 5.2. An underwater buoy was used to prevent wave motions on the surface to be transmitted to the collectors so that the sediment material was stirred up (resuspended). For the same reason the sediment traps were taken up to the surface very carefully. Before being deployed, a few drops of chloroform was added to the traps to reduce grazing and bacterial decomposition of the material collected (BLOESCH and BURNS 1980, BLOMQVIST and HÅKANSON 1981).

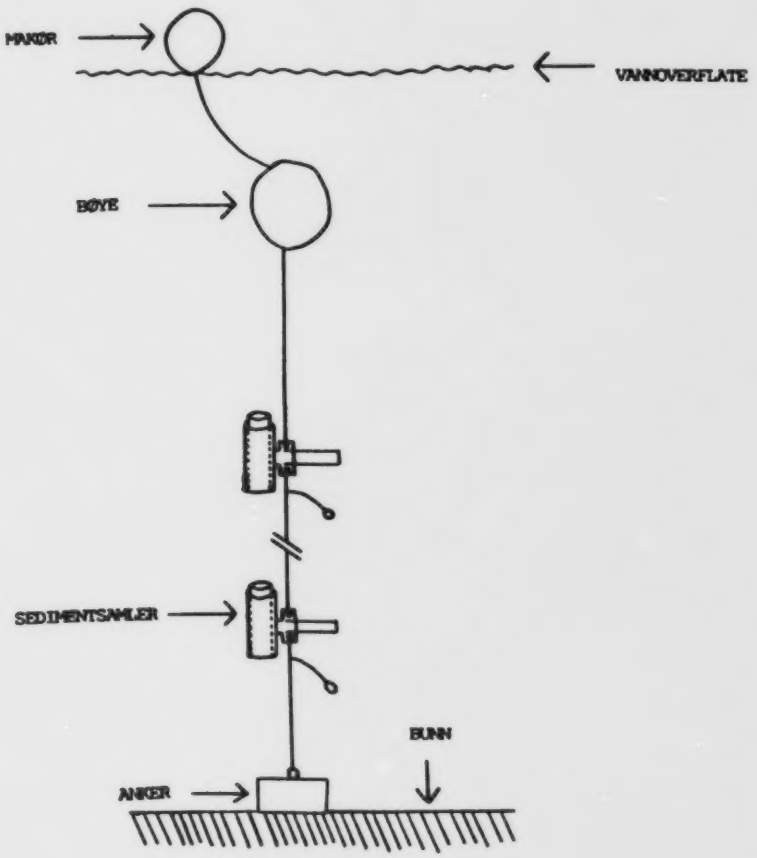


Fig. 5.2. Rigg med sedimentsamlere.

Rig with sediment traps.

5.4.2. Farms studied. (p.36)

Sedimentation was investigated at Farms 2 and 9 (Figs. 3.2 and 3.8). These are the same farms where nutrient salt studies were made (see Sect. 4).

Farm 2 is located in an outer fjord area to the leeward of some small islands that act to slow the currents down. In poor weather there will be some resuspension in the recipient due to groundswell. The location is further described in Sect. 3.1 and 3.2.

The installation produced 75 tonnes fish in 1984. A total of 160 tonnes dry feed was used. There was otherwise little loading on the recipient. For further information we refer to Sect. 3.3.

Farm 9 is more enclosed. The largest depth in the area is 89 m, with a sill where the water depth is 30 m. The bottom under the installation is located at the sill. Topography, hydrography and currents are described in Sect. 3.1 and 3.2. The production of the farm was 65 tonnes of salmon in 1984 with a feed consumption of 180 tonnes moist feed. The recipient is being stressed by several fish farms. Further information on Farm 9 and the recipient is given in Sect. 3.3.

5.4.3. Collection program.

Two rigs were placed at each farm at the same stations where samples for nutrient salts and benthos were taken. The locations of the stations are shown in Figs. 3.2 and 3.8. The upper sediment trap was placed 10 m under the surface; the lower at least 5 m above the bottom to reduce the effect of re-suspension. The middle trap at station 9.3 was placed directly over the sill deep (See Table 5.1).

The sediment traps were left for 21 to 44 days between each time they were emptied. Further information is given in Table 5.2.

Tabell 5.1. Måledyp, totaldyp og stasjonens avstand fra anleggene.

Measurement depth, total depth and distance from fish farms.

	stasjonsnummer			
	2.2	2.3	9.2	9.3
Måledyp	10 m 15 m	10 m 15 m	10 m 25 m	10 m 25 m 85 m
Totaldyp	20 m	28 m	30 m	89 m
Avstand fra anlegg (m)	120	250	120	260

Tabell 5.2. Utsettings- og innsamlingsdatoer, samt lengden av innsamlingsperiodene.
I perioden 030784 - 170784 (14 døgn) var samlerne på land for reparasjon.

Date when the traps were sat out, sampling date, and duration of sampling period.
Sediment traps were ashore during the period from 03.07.84 to 17.07.84 (two weeks) for repair.

Innsamlingsperiode	Lengde av innsamlingsperiode (døgn)
030584 - 050684	33
050684 - 030784	28
170784 - 070884	21
070684 - 030984	27
030984 - 031084	30
031084 - 291084	26
291084 - 121284	44
121284 - 160185	35
160185 - 120285	27
120285 - 130385	29
130385 - 100485	28
100485 - 140585	34
140585 - 180685	35

5.4.4. Analyses.

The contents of the sediment traps were transported to a laboratory for further processing. The samples were shaken thoroughly to obtain as homogeneous a distribution as (p.38) possible and aliquots were taken. Three replicate samples were taken from each parameter. The particulate material in the aliquots was filtered through filters suitable for the various analyses. It was attempted to keep the volume of the filtrate constant. In some samples the volume had to be reduced since the samples contained large numbers of particles that plugged the pores in the filters.

Table 5.3 gives an overview over the parameters investigated and references to the analytical methods used.

Tabell 5.3. Oversikt over de parametrene som ble analysert med referanser til metodebeskrivelse. Tabellen gir også de vanlige forkortelsene av undersøkte parametre.

Overview of the analysed parameters with reference for the method employed. The table also gives common abbreviations for the parameters.

Parameter	Forkortelser	Referansenr.
Totalt partikulært materiale	TPM	(1)
Partikulært uorganisk materiale	PUM	(1)
Partikulært organisk materiale	POM	(1)
Partikulært organisk karbon	POK	(2)
Partikulært organisk nitrogen	PON	(2)
Totalt partikulært fosfor	TPF	(3)
Klorofyll a ekvivalenter	KLO a ekviv.	(4)

See p. 45

Referanser:

1. DEAN (1974), MOOK and HOSKIN (1982)
2. PELLA (1978)
3. GRASHOFF (1976)
4. YENTSCH and MENZEL (1963), HOLM-HANSEN et al. (1965), HENDRIKSON (1975).

5.5. Results

All the results are presented in Appendix 2. Information on monthly feed consumption is given in Fig. 3.11.

The daily sedimentation rate of total particulate material (TPM) at both installations is shown in Fig. 5.3. The figure also shows particulate organic carbon (POK) in percent of total particulate material.

The sedimentation rates for TPM in 10 m at all stations fluctuated with the seasons of the year with low values in January - February. The measurements at the largest depth at Station 9.3 differed by having high sedimentation rates, especially in May and June 1984. This is most probably caused by re-suspension in connection with inflow of new water to the area in this period (see Fig. 3.9. regarding the oxygen conditions at Station 9.3).

The sedimentation rates were markedly higher near the installations (Stations 2.2 and 9.2) than they were further out in the recipient (Stations 2.3 and 9.3). This was most obvious in the enclosed area near Farm 9, and the difference was greatest in the upper part of the water column (more shallow than 10 m).

In the more exposed recipient at farm 2 the differences in the sedimentation rates at 15 m depth appear to be less affected by the distance from the installation.

The percentage content of particulate organic carbon in the sedimented material was lowest in the period from October to February at farm 2. At Farm 9 the content of particulate organic carbon was somewhat higher. The content of organic material was highest near the installations (solid lines). This was especially noticeable at Farm 9. The deep measuring point at Station 9.3 differed by having less pronounced seasonal variations POK expressed in percent of TPM.

Figure 5.4 shows the daily sedimentation rates for particulate organic carbon (POK) and the ratio between the number of carbon and nitrogen atoms C/N value).

The sedimentation rates of POK showed clear seasonal variations, with low winter- , and high spring- and summer values. This was less pronounced at the deepest measuring point at Station 9.3. High values in May-June are probably due to re-suspension in connection with inflow of water.

The ratio between POK and PON (C/N value) was most stable at Farm 2. The relationship was little affected with distance from the farm or the depths and were in the range (p.40) from 8 to 15. The C/N values at Farm 2 seemed to be highest in the period July - January, and lowest in late spring and early summer.

At Farm 9 the C/N values fluctuated markedly both with the distance from the installation and with the depth. At 10 m depth there were minima in October and February and maxima in June-July, December and April at both stations. This was most pronounced at Station 9.3 that was located the furthest distance from the farm; the values here fluctuated between 7 and 16. At 25 m depth there was also good agreement between the two stations, but the C/N values were more stable than at 10 m depth. Also here there were high values in November - December and low in February - March.

At 85 m depth at station 9.3 the C/N values were between 9 and 16 and these fluctuated less than higher up in the water column.

Sedimentation of particulate organic nitrogen (PON) is shown in Fig. 5.5. The figures also show the relationship between the number of nitrogen - and phosphorus atoms.

Sedimentation of PON and POK showed great similarities both with respect to seasonal variations and the effects of distance from the farm and depth. The sedimentation rates for PON will therefore not be discussed separately. However, the atomic ratio between N and P differ from the C/N values. PON/TPF showed a pronounced seasonal variation with low values in the period August - January. This was most pronounced in the upper part of the water column. There was, however, little difference between

the two stations at each farm. The distance from the installation therefore seems to be of minor importance.

The sedimentation rates of TPF from the whole study period are given in Fig. 5.6. The figures also show the ratio of carbon and phosphorus atoms in the sedimented material.

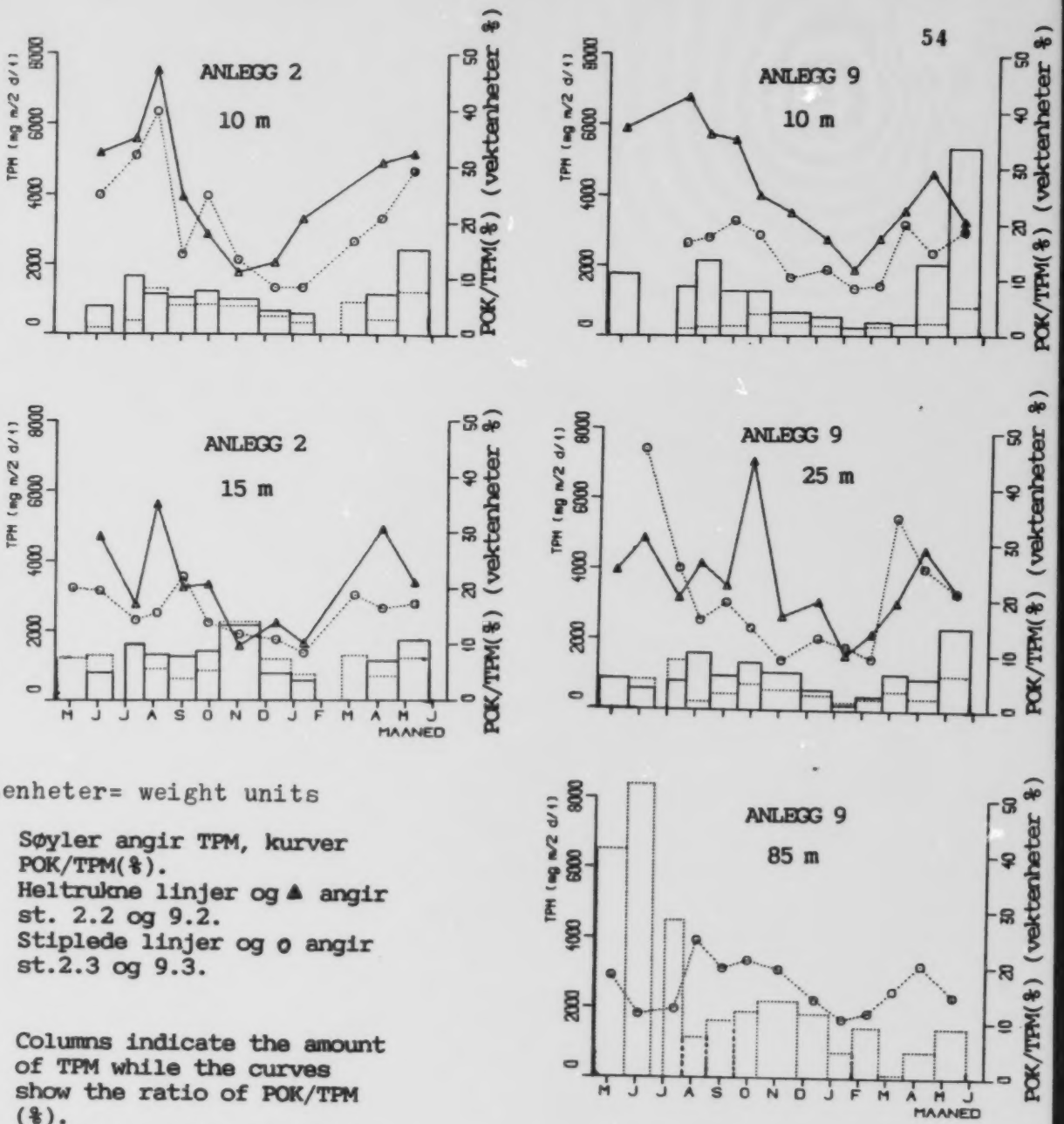
At both installations the sedimentation rate for TPF was highest near the farms. This was the case both at 10, 15 and 25 meter depths. The sedimentation rates were lowest from November to February. The difference in the sedimentation for TPF between the stations was highest at Farm 9.

The ratio between POK and TPF exhibited the same trend as the PON/TPF ratio, and this ratio will therefore not be further discussed here.

Fig. 5.7 shows daily sedimentation rates for chlorophyll a equivalents (KLO a equiv.) and the ratios between particulate carbon (POK) and KLO a equiv.

The high sedimentation rates of KLO a equiv. in May 1984 and in March 1985, especially at station 9.2, 10 m, are due to the yearly bloom of diatoms. Diatoms bloom in large concentrations in the spring, and when they have used up most of the nutrients in the area, the algae die and sediment out of the water masses. At station 2.2 the sediment traps were not deployed in the same periods as at station 9 (See Table 5.2).

High POK/KLO a equivalents indicate that the supply of particulate organic carbon does not originate from the phytoplankton (primary producers).. From Fig. 5.7 it can be seen that POK/KLO a equivalents were highest near the farms. At Farm 2 the values were highest at 10 m depth in late summer 1984 and the spring of 1985. At Farm 9 the values at station 9.2, 10 m depth were especially high in late summer 1984 and at 25 m depth in the spring of 1985.



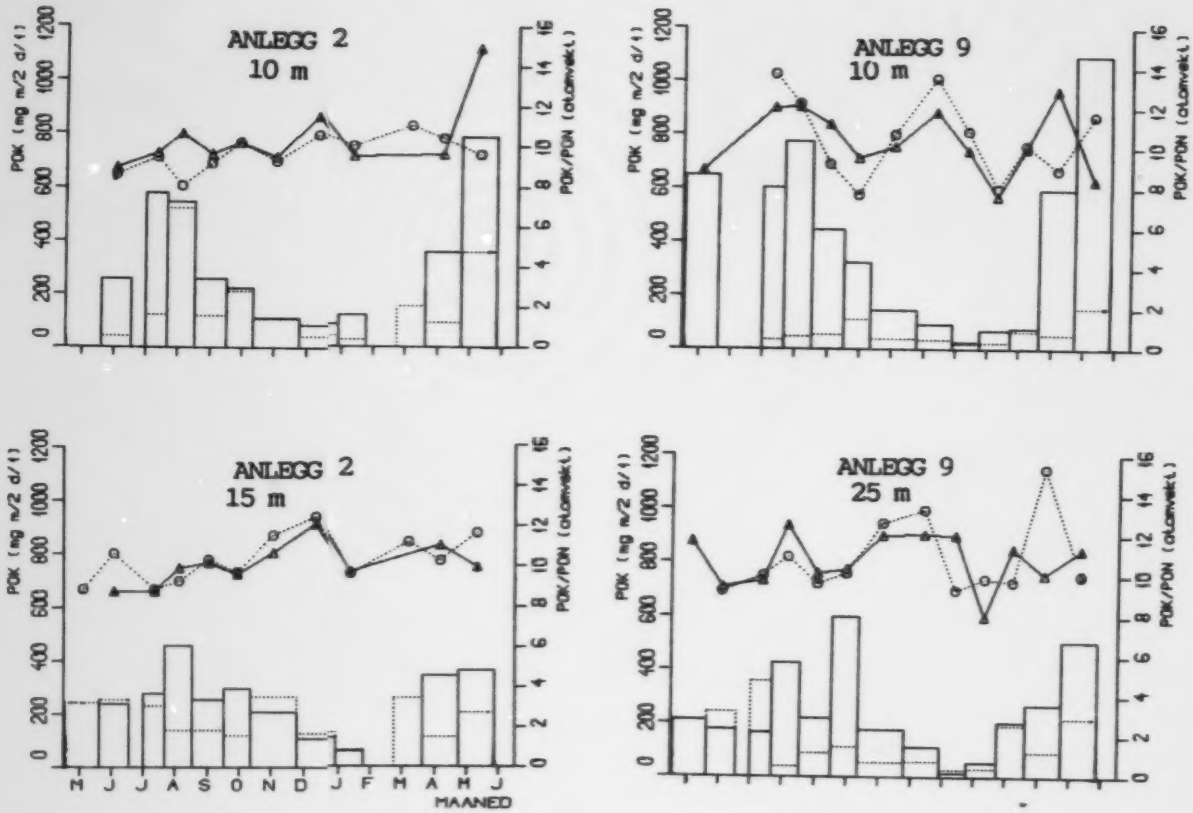
vektenheter= weight units

Søyler angir TPM, kurver POK/TPM(%).
Heltrukne linjer og ▲ angir st. 2.2 og 9.2.
Stiplede linjer og o angir st.2.3 og 9.3.

Columns indicate the amount of TPM while the curves show the ratio of POK/TPM (%).
Solid line and ▲ illustrate station 2.2 and 9.2.
Dashed line and o illustrate station 2.3 and 9.3.

Fig. 5.3. Daglig sedimenteringsrate av totalt partikulært materiale (TPM) utrykt i mg m^{-2} d^{-1} (TPM) og det prosentvise innhold av partikulært organisk karbon (POK) i forhold til TPM ved anlegg 2 og 9 i perioden mai 84 - juni 1985.

Daily sedimentation rates of total particulte material (TPM) in mg m^{-2} d^{-1} and the relative percentage of particulate organic carbon (POK) to TPM at fish farm 2 and 9 from May 1984 to June 1985.



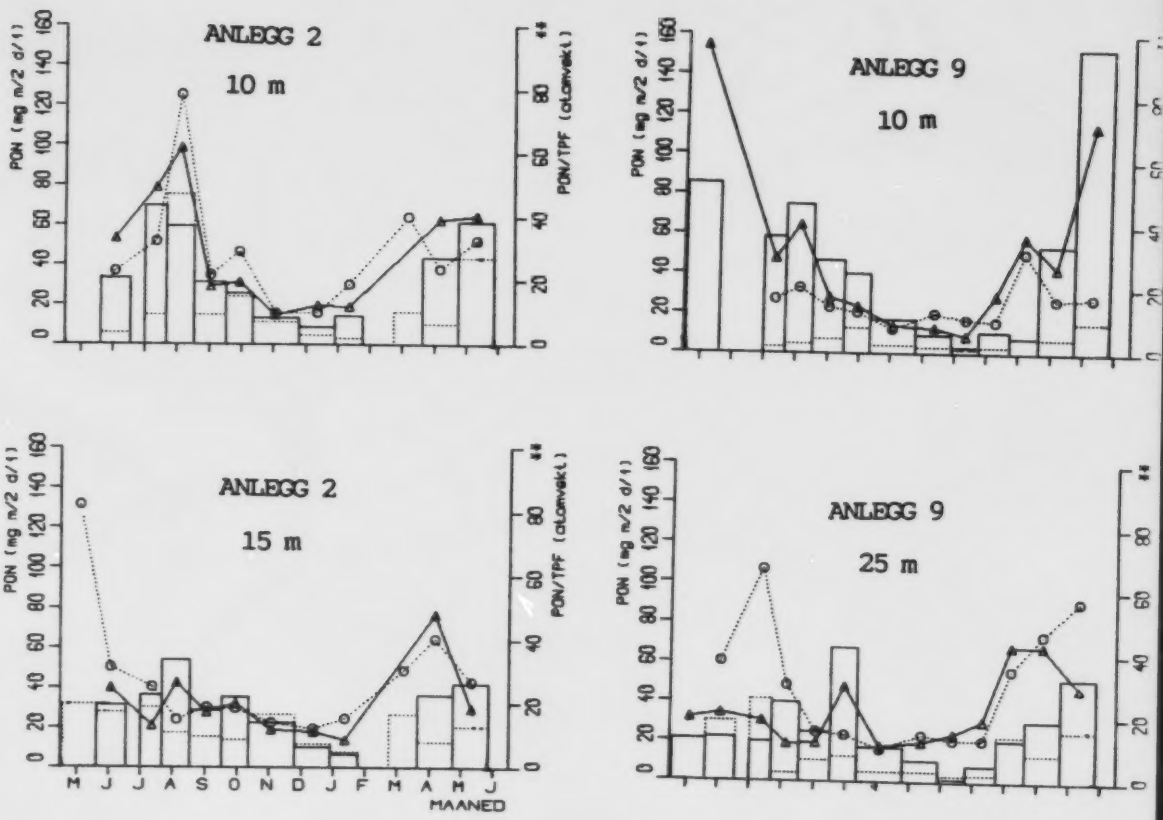
atomvekt=atomic weight

Søyler angir POK, kurver forholdet mellom antall karbon- og nitrogen-atomer. Heltrukne linjer og ▲ angir st. 2.2 og 9.2. Stiplede linjer og ● angir st.2.3 og 9.3.

Columns indicate the amount of POK while the curves show the ratio of carbon to nitrogen atoms. Solid line and ▲ illustrate station 2.2 and 9.2. Dashed line and ● illustrate station 2.3 and 9.3.

Fig. 5.4. Daglig sedimenteringsrate for partikulært organisk karbon (POK) uttrykt i mg m^{-2} d^{-1} og atomære forhold mellom partikulært organisk karbon og partikulært organisk nitrogen (PON) (C/N - verdier) ved anlegg 2 og 9 i perioden mai 84 - juni 1985.

Daily sedimentation rates of particulte organic carbon (POK) in mg m^{-2} d^{-1} and the atomic ratio between POK and particulate organic nitrogen (PON) (C/N ratio) at fish farm 2 and 9 from May 1984 to June 1985.

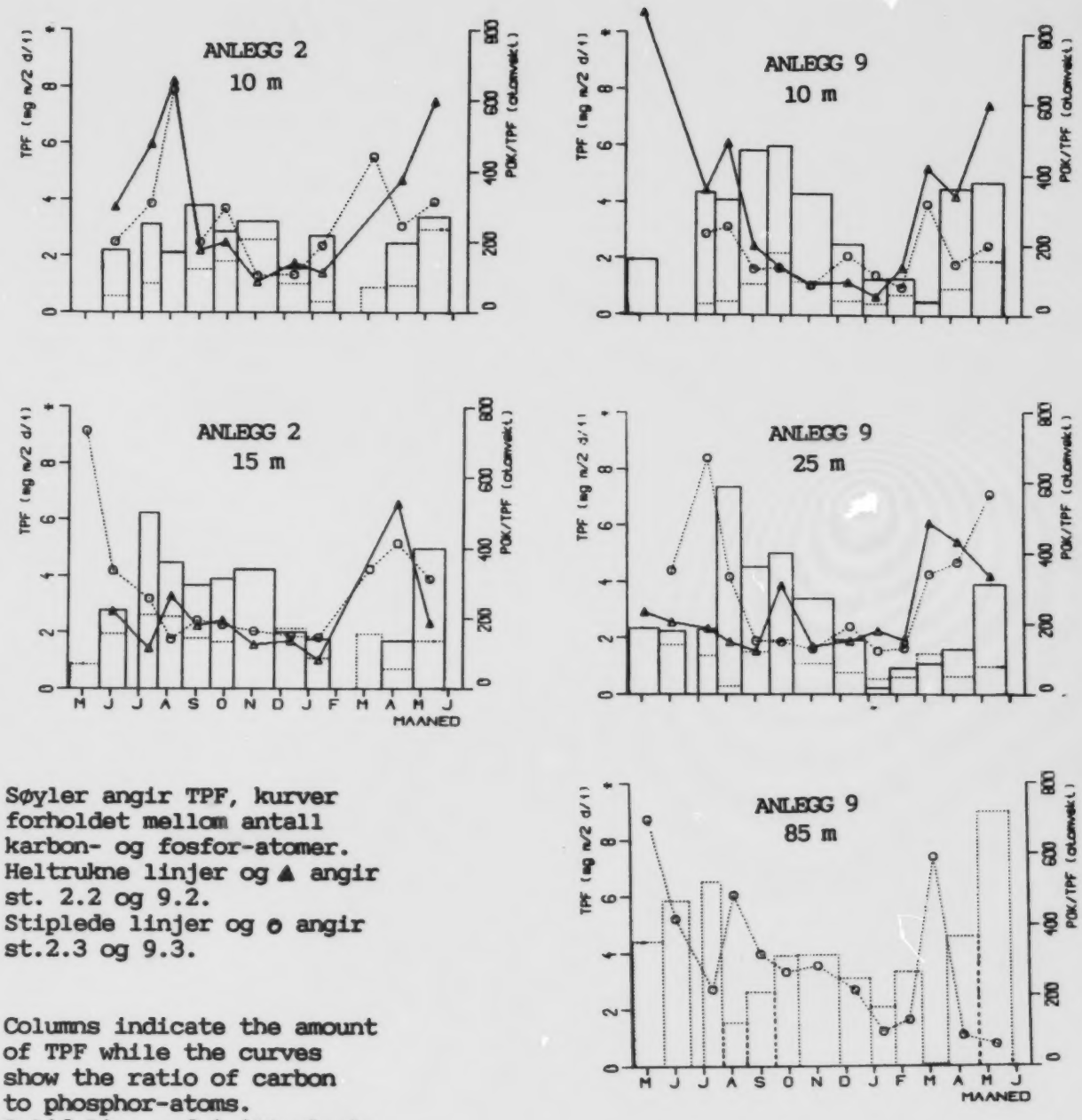


Søyler angir PON, kurver forholdet mellom antall nitrogen-og fosfor-atomer. Heltrukne linjer og ▲ angir st. 2.2 og 9.2. Stiplede linjer og o angir st.2.3 og 9.3.

Columns indicate the amount of PON while the curves show the ratio of nitrogen to phosphor-atoms. Solid line and ▲ illustrate station 2.2 and 9.2. Dashed line and o illustrate station 2.3 and 9.3.

Fig. 5.5. Daglig sedimenteringsrate for partikulært organisk nitrogen (PON) uttrykt i mg m^{-2} d^{-1} og det atomære forhold mellom PON og totalt partikulært fosfor (TPF) ved anlegg 2 og 9 i perioden mai 84 - juni 1985.

Daily sedimentation rates of particulte organic nitrogen (POK) in mg m^{-2} d^{-1} and the atomic ratio between PON and the total particulate phosphate (TPF) at fish farm 2 and 9 from May 1984 to June 1985.

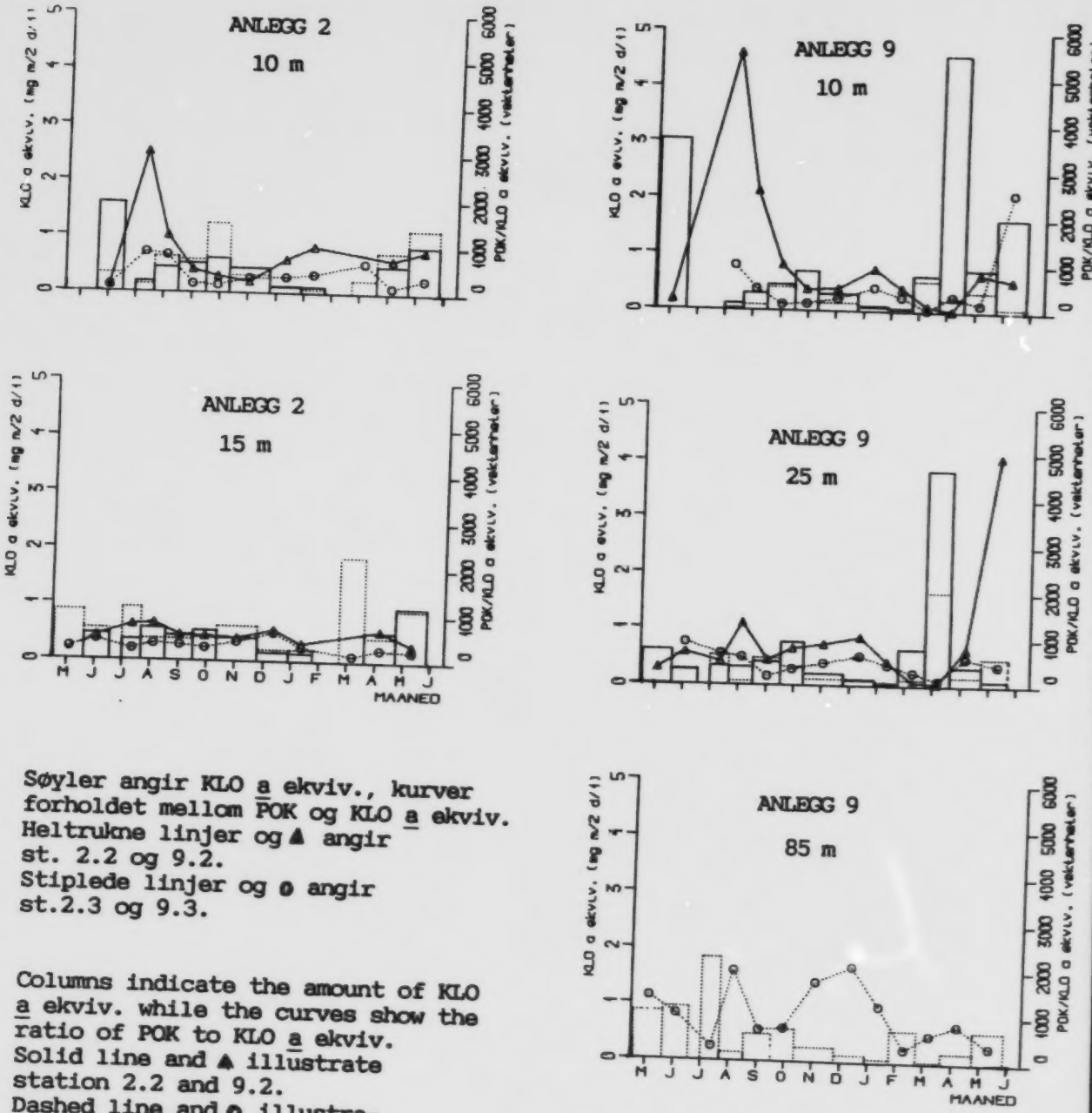


Søyler angir TPF, kurver forholdet mellom antall karbon- og fosfor-atomer. Heltrukne linjer og ▲ angir st. 2.2 og 9.2. Stiplede linjer og o angir st.2.3 og 9.3.

Columns indicate the amount of TPF while the curves show the ratio of carbon to phosphor-atoms. Solid line and ▲ illustrate station 2.2 and 9.2. Dashed line and o illustrate station 2.3 and 9.3.

Fig. 5.6. Daglig sedimenteringsrate for totalt partikulært fosfor (TPF) uttrykt i mg m^{-2} d^{-1} og det atomære forhold mellom POK og TPF ved anlegg 2 og 9 i perioden mai 84 - juni 1985.

Daily sedimentation rates of total particulte phosphate (TPF) in mg m^{-2} d^{-1} and the atomic ratio between POK and TPF at fish farm 2 and 9 from May 1984 to June 1985.



Søyler angir KLO a ekviv., kurver forholdet mellom POK og KLO a ekviv. Heltrukne linjer og ▲ angir st. 2.2 og 9.2. Stiplede linjer og ● angir st.2.3 og 9.3.

Columns indicate the amount of KLO a ekviv. while the curves show the ratio of POK to KLO a ekviv. Solid line and ▲ illustrate station 2.2 and 9.2. Dashed line and ● illustrate station 2.3 and 9.3.

Fig. 5.7. Daglig sedimenteringsrate for klorofyll a ekvivalent (KLO a ekviv.) uttrykt i mg m^{-2} d^{-1} og forholdet mellom partikulært organiske karbon (POK) og KLO a ekviv. ved anlegg 2 og 9 i perioden mai 1984 og juni 1985.

Daily sedimentation rates of chlorophyll a equivalents (klo.a.-ekvi.) in mg m^{-2} d^{-1} and the ratio between POK and klo.a.ekvi. at fish farm 2 and 9 from May 1984 to June 1985.

5.6. Discussion

5.6.1. Physical and biological characteristics at the measuring stations.

Both the installations are located in transition zones (mixture of coastal water and fjord water, see Sect. 3.2). They are closely connected with a larger fjord system, and are characterized biologically by this.

5.6.2 Sedimentation rates in upper water layers.

The TPM sedimentation rates are not higher than those found in other sedimentation studies in Western Norway (WASSMANN 1983, 1984, 1985; SKJOLDAL and WASSMANN 1986; ORDEMANN 1987). The sedimentation rates of POK, PON, TPF and KLO a equivalents were in contrast at times clearly higher. Normal sedimentation rates for the above mentioned parameters are shown in Table 5.4.

Tabell 5.4. Normale sedimenteringsrater for undersøkte parametre i øvre vannlag.

Common sedimentation rates in the upper layers for the parameters investigated.

POK	200	- 300	mg m^{-2}	d^{-1}
PON	20	- 30	"	
TPF	1	- 3	"	
KLO a ekviv.	0.1	- 0.3	"	

In this study it was not unusual to find sedimentation rates for POK > 500 mg m^{-2} d^{-1}, for PON > 40 mg m^{-2} d^{-1}, for tpf > 4 mg m^{-2} d^{-1} nd KLO a equiv. > 0.6 mg m^{-2} d^{-1}. The highest sedimentation rates for POK, PON, TPF and KLO a equiv. were found especially at St. 9.2 at 10 m, but also St. 2.2 at 10 m could at times have such high sedimentation rates (Fig. 5.4, 5.5, 5.6).

5.6.3. The sedimentation rates in the upper water layers compared with feed consumption.

The sedimentation rates for TPM, POK, PON and TPF near the farms follow approximately the feed use, and have the highest values in the summer and fall when feed use is high (Fig. 5.3, 5.4, 5.5 and 5.6). The sedimentation of KLO a equiv. has, however, the highest values in March - April after the spring bloom.

5.6.4. Comparison of sedimentation rates in upper water layers in a gradient out from the farm.

Other studies of sedimentation rates in areas where there are farm installations have measured high sedimentation directly under the farms, partly also at a control station a considerable distance from the farm (ERVIK, JOHANNESSEN and AURE 1985, HALL and HOLBY 1986).

ERVIK et al (1985) found sedimentation rates for POM that were ca 500 times higher than the sedimentation rates in the water masses at 10, 15 and 25 m in this study. TPN, POK, TPM and TPF had clearly higher sedimentation rates near the farms. This was especially pronounced at Farm 9. The sedimentation of KLO a equiv. was clearly higher near the farms. It is obvious that the operation of the farms will result in increased sedimentation in the immediate area. The benthos studies (Sect.6) exhibit similar local effects.

5.6.5. Composition of the sedimented material in upper water layers.

The material that sedimented had at times a very high content of organic materials. PUM/TPM (%) and POK/TPM (%) give information on the inorganic and organic contents of the sedimented material. PUM/TPM (%) constitutes normally ca 60% in the spring, summer and fall, and 80% or more in the winter. POK/TPM (%) is normally ca 20% or less (SMETACEK 1984). The

lowest ratios for PUM/TPM (%) measured in this study, was 31.2 and 13.4 at 10 m, respectively at Sts. 2.2 and 9.2. As for TPM, POK, PON and TPF this was clearly related to feed use.

ERVIK et al.(1985) found that PUM/TPM (%) in the sediment immediately under the cages was ca 42% in periods of heavy feeding. Corresponding values were found in the sedimented material both at Sts. 2.2 and 9.2, and in part at St. 2.3 at all depths (Appendix 2). This shows that the material being sedimented immediately under the farms is similar to that being sedimented around the farms. It is also clear that sedimentation rates and compositions of the sedimented material are determined by the feeding intensity at the farms.

Even if the organic content was very high in the sedimented material, the material that was sedimented through large parts of the study was strongly refracted. i.e. much decomposed. This can be seen especially from the C/N values, but is also indicated by POK/TPF, PON/TPF and the ratios between POK and KLO a equiv.

It was only from February to March 1985 at St. 9.2 (p.49) at 10 and 25 m that the C/N values were <9 (Fig. 5.4). Material that has C/N values > 9 is considered to be strongly decomposed. FUKAMI, SIMUDU and TAGA 1985). The results are probably related to the high sedimentation rates of KLO a equiv. (Fig. 5.7) in this period, and with low feeding rates (Fig. 3.11).

High C/N - values are common in the winter when the biological activity is very low, while it is usual to find C/N - values around 8 or lower in the spring, summer and fall (WASSMANN 1983, 1984, 1985, ORDEMANN 1987). An average C/N-value of ca 10.4 for the whole study period at 10 m deep at for example St. 2.2 and 9.2 is extremely high (Fig. 5.4). This can be due to two conditions:

1. The supply of organics from the farms increases the biological production and activity so much that recirculation of material becomes very high (WASSMANN 1985, ORDEMANN 1987), something that results in high C/N - values (HANSEN and RASK 1985). Stimulation of the biological activity due to feed waste from fish farms is

also mentioned in Sect. 6, and by ERVIK et al (1985).
2. The high C/N - values can also be due to the fact that the waste itself has a high content of carbon compared with the nitrogen content. High C/N - values, but low sedimentation rates of POK indicates that this is not the case.

The ratio between POK and TPF, and between PON and TPF is also highest when nutrient particles are recirculated. The recirculation is highest in the fall. In the winter and at "new" production, the atomic ratios between POK and TPF and between PON and TPF are lowest (SMETACEK 1984). "New" production means the primary production caused by a fresh supply of nutrient salts due to an upwelling of water masses, or by nutrient salts supplied by human activity (EPPLY and PETERSON 1979). The atomic ratios between POK and TPF and between PON and TPF is normally between respectively 100 to 300 and 10 to 30 (WASSMANN 1983, 1984, 1985, ORDEMANN 1987).

The ratio between POK and TPF was extremely high in the spring of 1985. At 10 m depth at Sts. 2.2 and 9.2, the ratios were ca 600. Similar values were found at station 9.2 in May 1984 (Fig 5.6). As for the other results, this seems to be associated with high feed use.

The same was the case for the ratio between PON and TPF which had values of 40 to 71 respectively at stations 2.2 and 9.2 at 10 m (Fig. 5.5). In addition, the ratio between PON and TPF was very low at St. 9.2 at 10 m from October (8.67) to the middle of February (5.49) (Appendix 2), i.e. high phosphorus content relative to the nitrogen content. The high sedimentation rates for TPF can be due to : (p.50)
1. supply from feed and excrements that dissolve directly in the water, or
2. resuspension from the sediment under the farm.

Orthophosphate that has been in anoxic environment can bind itself to particles in oxygenated water masses E.PAASCHE,

personal communication). The sediments under the farms contain large quantities of orthophosphate, and the environment here is often anoxic. HALL and HOLBY (1986) has found that the sediment under the cages can leak from 1-2 mmole m^{-2} into oxygenated water masses during the cultivation period. The high sedimentation rates of TPF are probably caused by re - suspension from the sediment under the farm (See Sect. 4).

POK/KLO a equiv. is lowest in the spring and fall during the large phytoplankton blooms, and highest during winter and summer. During a bloom, the ratio for the sedimented material is normally between 200 and 300. In winter and summer the values for the ratio fluctuate sharply; values from 600 to ca 1500 have been measured in earlier studies (SMETACEK 1980, WASSMANN 1983, 1984, 1985, ORDEMANN 1987). In this study extreme values of 3031 and 5515 were measured in the summer of 1984 at 10 m depth at respectively Stas.2.2 and 9.2. This shows that the pigment content of the sedimented material was very low. The most extreme ratios for POK/KLO a equiv. were therefore also found when feeding was at the highest level. Correspondingly high values were not found at Sts. 2.3 and 9.3.

The yearly sedimentation of POK closest to the farms (Sts. 2.2 and 9.2) at 15 - 25 m depths was 70 - 80 g m^{-2} $year^{-1}$. At Sts. 2.3 and 9.3 it was reduced to about 50 g m^{-2} $year^{-1}$. Compared with the results for comparable studies in Western Norway (SKJOLDAL and WASSMANN 1986, WASSMANN 1983, 1984, 1985), the yearly sedimentation of POK at Sts. 2.3 and 9.3 was low. However, near the farms it was at the same level as in earlier studies. (Fig. 5.58).

The present study shows, however, that the water masses at the farms were affected by their operation. This is especially noticeable in the composition of the sedimented material, but the differences between the sedimentation close to, and some distance from the farms, were also pronounced.

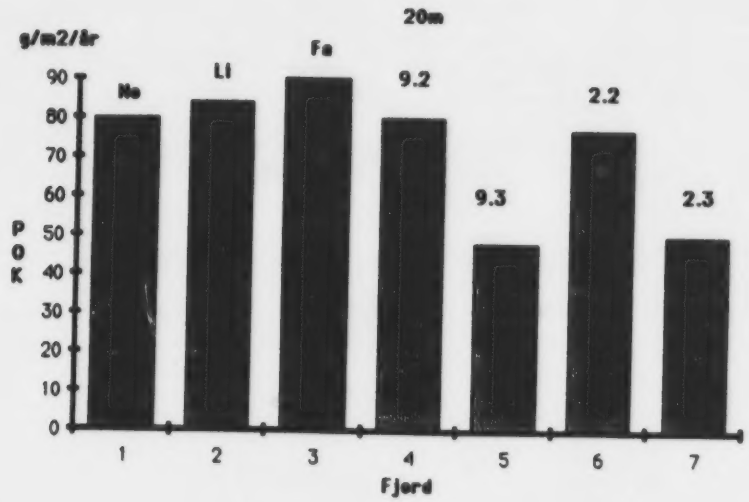


Fig. 5.8. Årlig sedimentering av POK i omlag 20 m dyp i Nordåsvannet (NO), Lindåspollene (LI), Fanafjorden (FA) 60 m dyp, st. 2.2 og 2.3, st. 9.2 og 9.3.

Annual sedimentation of POK at 20 m depth in Nordåsvannet (NO), Lindåspollene (LI), Fanafjorden (FA) at 60 m depth, and station 2.2, 2.3, 9.2, and 9.3.

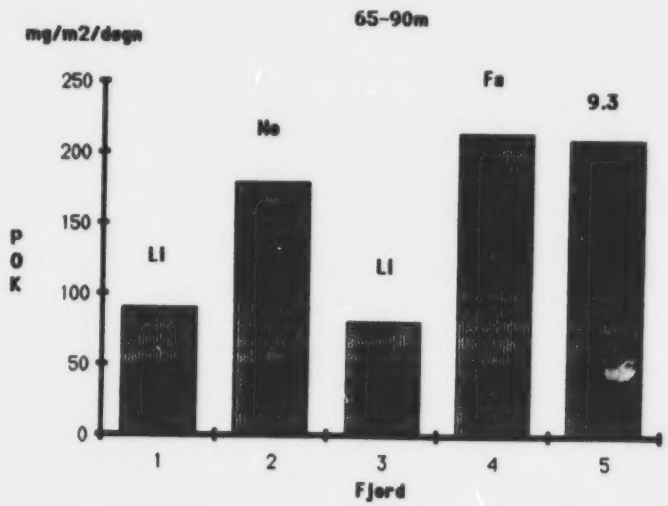


Fig. 5.9. Midlere sedimenteringsrate av POK i 65-90 m dyp i Nordåsvannet (NO), Lindåspollene (LI), Fanafjorden (FA) og ved st. 9.3. (1 - LI 1982, 3 - LI 1981).

Average sedimentation rate of POK at 65-90 m depth in Nordåsvannet (NO), Lindåspollene (LI), Fanafjorden (FA) and at station 9.3 (1 - LI 1982, 3 - LI 1981)

5.6.6. The ratios at St. 9.3, 85 m depth

As mentioned in Sect. 3.3, there were several other fish farms in the area of St. 9.3. The basin will therefore function as a recipient for all the fish farm installations in the area.

The content of organic carbon in the sedimented (p.52) material in the fall, i.e. from August to December 1984 at St. 9.3 at 85 m depth, was relatively high considering the depth. In the Lindås Polls (small fjord with narrow inlet) and in the Fana Fjord, values that were 25% lower have been found (WASSMANN 1984, ORDEMANN 1987). The increased organic content in the sedimented material can be caused by the fish farms in the area.

From May to June 1984 the sedimentation rates for TPM, PUM and POK were high in relation to the rest of the collection period (Fig. 3.9). The high sedimentation rates in this period are therefore probably the result of natural hydrographic conditions.

Yearly average sedimentation rate of POK at 85 m depth at St. 9.3 was at the same level as observed in the Fana Fjord and Nordås Lake. The Lindås Fjord (Poll) has about half the values due to lower production (Fig. 5.9) (WASSMANN 1983, 1984, 1985). The Nordås Lake and Lindås Fjords are typical "polls" , so that the conditions in the Fana Fjord is most comparable with the conditions at St. 9.3. It therefore seems that the relatively large production of fish in the area near St. 9.3 has had little effect on the supply of POK to the deep water. The oxygen consumption of 0.8 - 1.0 ml/l/month in the deep water at St. 9.3 still appears to be somewhat high when related to comparable basins.

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6. BENTHIC FAUNA (p.53)

6.1. Summary

Benthic fauna and sediment was studied in 1984 and 1985 at nine fish farms, four in South Tröndelag and five in Hordaland counties. Factors such topography, hydrography, currents, runoff from land, farm size and feeding routines resulted in special situations for each farm. It is therefore difficult with todays knowledge to evaluate the effect from individual farms based on general guidelines. Each aquaculture location must therefore be studied and evaluated separately. The effects of each installation were in most cases local, but in some enclosed areas larger areas of the recipient were affected. Benthic fauna studies compared with sediment observations see to be a suitable method to monitor recipients with fish farms. Simple beach investigations were conducted at the farms. The results show that the effect on the littoral (beach) zone was low and very local.

6.2. Objectives

The objectives of this part of the study were:

1. To study to which degree food fish installations affect benthic fauna and the littoral zone.
2. Give a situation account of benthic fauna and sediment at food fish installations.
3. Collect reference material that can later be used for comparison to demonstrate changes in the conditions near the installations.

6.3. Materials and methods

6.3.1. Collection program

Four farms were studied in South Tröndelag county, two in may 1984 and two in June 1985. In Hordaland county , five farms were investigated, two in May 1984 and two in June 1985. In

Hordaland county five farms were studied, two in May 1984 and three in May 1985. Equipment was placed at our disposal by the Institute of Marine Biology, The University in Bergen, that also supplied a vessel for the collections in Rogaland county. The M/V "Skagholm" was used for the collections in Sör-Tröndelag.

Outline maps are shown in Figs. 3.1-3.8 over the areas with the individual sampling stations indicated. Operating data from the farms is tabulated in table 3.5. The sampling stations at each installation are numbered consecutively by farm number. For practical and economic reasons, the samples had to be collected over a two year period. The data for the sample collection is presented in Table 6.1.

6.3.2. Sediment investigations

From a grab sample at each station, sediment samples were taken through a hatch at the top of the grab (Fig. 6.1). The sediment sample was analyzed for size composition of particles, and the content of organic material was determined by a simple ignition loss analysis. Particle distribution was studied by wet screening of the sediment (FOLK 1968). For particles less than 0.063 mm, pipette analysis was employed. The content of organic material was determined according to a method published by MOUM (1967).

The analyses of particle distribution and organic content in the sediment were performed by cand. real. H.Grönning.

6.3.3. Benthic fauna investigations.

The number of stations and the placement of these is decided by the topographical conditions and the location of the farm. Attempts were made to locate the sampling stations along an assumed pollution gradient from the installations and out towards unaffected areas.

Fig 6.1

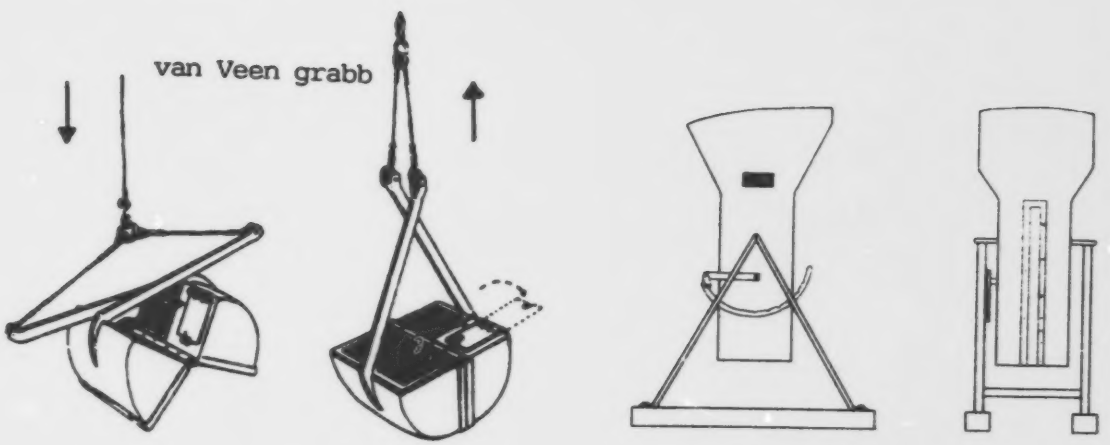

Fig. 6.1. Grabb og volummåler. (Tegningen av grabben er hentet fra BRATTEGARD og HØISÆTER 1972).

Grabb and volume measuring device (drawings from BRATTEGARD and HØISÆTER 1972).

Tabell 6.1. Stasjonsopplysninger fra prøver tatt på tilsammen 9 matfiskanlegg i Sør-Trøndelag og Hordaland. Tabellen angir innsamlingsdato, dyp, antall grabbprøver og volumet av prøvene. Full grabb inneholder 48 liter. Det er også gitt en kort beskrivelse av sedimentet.

Information on sampling stations at 9 fish farms in Sør-Trøndelag and Hordaland. The table provides sampling dates, sampling depth, sample numbers and volumes. Maximum grab sampling volume is 48 l. A short description of the sediments is given.

Anlegg nr. / Farm	Stasjons-nummer / Station	Dato	Dyp (m) / Depth	Hugg-nummer / Sample	Volum av prøven (l) / Sample vol.	Andre opplysninger / Other info.
1	1.1	230584	16	1	20	Fin skjellsand
				2	16	Fine shellsand
				3	16	
				4	15	
				5	15	
	1.2	230584	18	1	20	Fin skjellsand
				2	16	
				3	16	
	1.3	230584	41	1	21	Fin sand
				2	20	
	1.4	230584	5	1	5	Fin skjellsand
				2	2	
2	2.1	030584	18	1	20	Fin skjellsand.
				2	23	H_2S-lukt odor
	2.2	030584	20	1	15	Sandbunn med store Sandy bottom
				2	15	kuskjell. Svak H_2S- with large
				3	14	lukt.
				4	17	ocean quahaug Weak H_2S
				5	12	odor
	2.3	030584	28	1	15	Grov skjellsand
				2	14	Coarse
				3	16	
3	3.1	220584	25	1	8	Fin sandbunn/skjell-
				2	6	sand
				3	2	
				4	6	
				5	1	
	3.2	220584	61	1	48	Brown [illegible] sediment. Svak
				2	48	H_2S-lukt. Mye organ- Much org.ma
				3	48	isk materiale
	3.3	220584	61	1	48	Tyntflytende muddar. Thin-flowin
						H_2S-lukt (liquid) mud
	3.4	220584	77	1	48	Muddar. H_2S-lukt
				2	48	
				3	48	
	3.5	220584	49	1	15	Skjellsand
	3.6	220584	86	1	48	Muddar
4	4.1	080585	44	1	48	Black Svart H_2S-holdig se-
						diment uten dyreliv W.O. animal
						life.
	4.2	080585	30	1	8	Fin sand. Mye dyr. Many animals
						Litt forlukt Little feed odor
	4.3	080585	54	1	-	Fjell. Ikke mulig å Rocky. No
						få hugg sample
	4.4	080585	53	1	3	Fin sandbunn

Tabell 6.1. Forts.

Anlegg nr.	Stasjons-nummer	Dato	Dyp (m)	Hugg-nummer	Volum av prøven (l)	Andre opplysninger
5	5.1	070585	23	1	48	Svart H_2S-holdig sediment uten dyreliv
	5.2	070585	15	1	20	Grov skjellsand med mudder. Mye døde skjell. Svak H_2S-lukt
	5.3	070585	12	1 2	20 28	Svart H_2S-holdig sediment. Skjellsand under mudderet
	5.4	070585	11	1 2 3	7 15 5	Fin til grov skjellsand
	5.5	070585	15	1	48	Råtten bunn med mye forrester
	5.6	070585	11	1 2 3	12 8 13	Fin skjellsand
6	6.1	030685	7.5	1 2 3	14 12 8	Sand og mudder
	6.2	030685	20	1 2 3	10 12 12	Sandblandet mudder
	6.3	030585	13	1 2 3	6 5 6	Fin skjellsand
	6.4	030585	25	1	9	Fin skjellsand
7	7.1	050686	7.5	1 2 3	7 17 15	Fin skjellsand
	7.2	050685	25	1 2 3	12 12 15	Fin sand med mudder
8	8.1	080585	28	1 2 3	2 1 5	Fin skjellsand. Svak forlukt
	8.2	080585	35	1 2 3	20 16 15	Skjellsand med mudder. H_2S-lukt
	8.3	080585	40	1 2 3	48 48 48	Brunt mudder med H_2S-lukt
	8.4	080585	12	1 2	14 15	Mudder og grov sand. Svak forlukt
9	9.2	040584	28	1 2 3	12 4 4	Skjellsand
	9.3	040584	85	1 2 3	48 48 48	Grått, fint sediment Svak H_2S-lukt
	9.4	040584	45	1 2 3	14 20 10	Fint, grått sediment

The samples were taken with a van Veen grab. The grab is a quantitative tool that takes samples of a given area of soft bottom - in this case 0.2 m^2. How deep the grab digs down depends on the hardness of the sediment. To get a measure of how much sediment there is in the grab, it was emptied into a volume measure and the volume read through a window on the measure (Fig. 6.1). A full grab contains 48 litres. The sediment was then washed through two screens (HOVGAARD 1973) where the first screen had 5 mm diameter holes and the second 1 mm. The samples are therefore for animals that are larger than 1 mm. The samples were preserved in 4% neutralized formalin.

In the laboratory the samples were screened again (smallest hole diameter 1 mm), the largest animals picked out directly and the smaller ones sorted under a binocular magnifier. The animals were then transferred to a suitable preservative for storage.

In Appendix 3 a short description is given of the methods used in processing the benthic fauna material.

6.3.4. Littoral zone investigations.

An inspection of the littoral zone was done at all the installations, and a closer registration was performed at two farms.

6.4. Results and discussion

To avoid that the discussion of the results becomes too difficult to follow, each farm will discussed separately following a brief introduction describing how the material was processed. A collective evaluation of all the material will then be given.

6.4.1. Sediment investigations

A description of the sediment as it was evaluated when the grab came up is give in Table 6.1. The grain distribution of the

sediment (particle size distribution) is presented in a figure during the discussion of each farm. The particle size is here set up along the horizontal axis and the percentage weight fraction (cumulative) along the vertical axis. Cumulative means that the weight of the different grain sizes is summed up until all the particles in the sample have been included, i.e. 100%.

The grain distribution of the sediment gives information on current conditions. In an area with good current conditions finer particles will be removed by the currents and the coarser particles remain. This will be reflected in the grain distribution which will show that most of the particles in the sediment are coarse. Similarly, in an area with weak currents, fine particles will sink to the bottom and be deposited in the sediment. The grain distribution curve will then show (p.58) that most of the particles are in the clay/silt fraction.

The ignition loss analysis is a method for measuring the organic content in the sediment. The results of the ignition loss analyses are shown in Table 6.2. Ignition losses over 10% are considered to be high and under 10% low.

6.4.2. Benthic fauna investigations

The information on the number of grab samples and sediment volume in the individual samples is given in Table 6.1. Complete lists of species for each farm is presented in Appendix 3. The benthic fauna material is kept at the Zoological Museum, the University in Bergen.

The species composition in the samples gives important information on conditions in the area. The bottom fauna gives a picture of conditions at the moment and also information on conditions in the past.

The list of species includes the whole material, also (p.59) animals that move freely on the surface of the sediment and plankton organisms that are captured by the open grab on the way down. Consideration has been given to this during processing of the data, and in the analyses only animals that the grab has

taken quantitative samples of are included. This means animals

Table 6.2

Tabell 6.2. Glødetap i sedimentet på de undersøkte stasjonene.

Percentage ash-free dry weight of the sediment at the stations investigated.

Stasjon	% glødetap
1.1	6.40
1.2	8.08
1.3	9.77
1.4	1.54
2.1	7.53
2.2	6.20
2.3	5.22
3.1	3.66
3.2	38.23
3.3	40.69
3.4	40.96
3.5	4.73
3.6	36.47
4.1	31.00
4.2	4.54
4.3	-
4.4	2.67

Stasjon	% glødetap
5.1	49.15
5.2	7.73
5.3	18.87
5.4	5.67
5.5	35.15
5.6	4.31
6.1	6.66
6.2	11.22
6.3	3.66
6.4	2.72
7.1	9.91
7.2	8.25
8.1	6.50
8.2	11.89
8.3	16.51
8.4	4.18
9.2	4.55
9.3	21.64
9.4	4.84

that live buried in the sediment of animals of low mobility that live on the sediment surface.

The following groups are included in the analyses: Sea anemones (Anthozoa), Priapulida, bristle worms (Polychaeta and Oligochaeta), Echiura, Sipuncula, Mollusca, Echinodermata and Ascidiacea.

Log-normal distribution

table 6.3 shows the number of species in the different geometric classes (see Appendix 3) at each station in the current investigation. The table also shows how many species and individuals the calculations are based on. The parts of the table of most interest are presented in the form of curves in the discussion of the individual farms. Reference is made to Appendix 3 for further presentation of the method. Forty to fifty species for three grab hauls is considered to be satisfactory.

The basis for the investigation was three stations at each farm with three grab samples at each station. However, the topographical conditions were so different from farm to farm that it was necessary to adjust the sampling procedure. At stations with dead bottom without animal life only grab sample was taken. In some areas only spot checks were made with a single grab sample. At five stations a total of five grab samples were taken. This was done to get especially good documentation. This variation in collection pattern made it possible to get a more complete picture within the economic framework established.

Tabell 6.3. Antall arter i de ulike geometriske klasser, antall arter totalt og antall individer som er inkludert i beregningen. Antall grabbhugg er anført.

Number of species of different geometrical classes, total number of species and number of individuals included in the calculation. Numbers of replicate samples are included.

	ANLEGG																	
	1				2			3						4		5		
	Stasjon				Stasjon			Stasjon						Stasjon		Stasjon		
Geometrisk klasse	1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	3.3	3.4	3.5	3.6	4.2	4.4	5.3	5.4	5.6
I	11	11	15	10	5	16	20	14	4	4	1	13	7	16	22	1	8	9
II	10	16	14	2	3	14	13	18	5	2	2	8	3	10	22	1	7	14
III	9	10	14	3	2	13	10	12	0	1	1	3	0	7	9	1	9	11
IV	5	6	6	2	1	7	3	8	0	0	0	3	0	5	3	1	3	9
V	6	5	3	1	0	9	2	6	1	1	0	0	0	2	2		2	6
VI	7	3	2	2	0	5	3	4	1		0	0	2	1	2		0	7
VII	1	3	4	1	0	3	1	0	1		0	1	0		1		0	0
VIII	0	1		2	0	3	0	2	2		0	1	0				0	1
IX	1	1			0	1	1		0		1		1				1	
X	3				2				1								0	
XI																	0	
XII																	1	
Antall arter (grupper) i analysene	53	56	58	23	13	71	53	64	15	8	5	29	13	41	61	4	31	57
Antall ind. i analysene	3087	1106	666	555	1483	1595	770	863	1155	40	460	347	421	222	389	18	3078	811
Antall bugg	5	3	2	2	2	5	3	5	3	1	3	1	1	1	1	2	3	3

No.of species

No of ind.

No. of samples

6				7		8				9		
Stasjon				Stasjon		Stasjon				Stasjon		
6.1	6.2	6.3	6.4	7.1	7.2	8.1	8.2	8.3	8.4	9.2	9.3	9.4
6	20	17	11	11	14	13	11	0	6	25	1	11
2	10	25	6	16	6	6	2	1	3	27	2	18
1	4	10	6	5	4	4	0		10	9	0	15
0	8	7	3	9	3	1	0		5	7	0	10
1	5	5	2	7	3	2	2		3	11	1	7
1	2	5	0	4	3	1	0		2	4	0	2
0	7	4	1	3	3	0	1		1	1	1	2
0	0	3		3	0	2	0			1		1
0	0			2	1	1	0					1
0	0				0		1					
1	0				1							
	1											
12	57	76	29	60	38	30	17	1	30	85	5	67
1242	3197	1498	208	2088	2237	851	1107	2	396	883	123	1181
3	3	3	1	3	3	3	3	3	2	3	3	3

Diversity (p.61)

Diversity (wealth of species and dominance) and evenness (see Appendix 3) was calculated for each station. The results are shown in Table 6.4.

Tabell 6.4. Antall arter og individer, diversitet og jevnhet (eveness) på alle stasjonene. Antallet hugg varierer endel fra stasjon til stasjon (se Tabell 6.3). Hmax står for maksimum diversitet (se vedleggsdel 3).

Number of species and individuals, diversity and eveness at all stations. Numbers of replicate samples varied from station to station (see Table 6.3). Hmax is the maximum diversity (see appendix 3).

Stasjons-nummer	Antall individer	Antall arter	Diversitet	Jevnhet	Hmax
1.1	3088	53	3.2084	0.5601	5.7279
1.2	1186	56	3.9631	0.6824	5.8074
1.3	665	58	4.4435	0.7585	5.8580
1.4	555	23	2.8106	0.6213	4.5236
2.1	1483	13	1.1759	0.3178	3.7004
2.2	1595	71	4.4482	0.7233	6.1497
2.3	772	53	3.1534	0.5505	5.7279
3.1	864	64	4.4306	0.7384	6.0000
3.2	1155	15	2.1744	0.5565	3.9069
3.3	40	8	1.9455	0.6485	3.0000
3.4	462	5	0.2201	0.0948	2.3219
3.5	347	29	2.3395	0.4816	4.8580
3.6	420	13	1.3579	0.3670	3.7004
4.2	222	41	4.3925	0.8199	5.3576
4.4	386	61	4.3059	0.7260	5.9307
5.3	18	6	1.6122	0.8061	2.0000
5.4	3073	31	1.0595	0.2139	4.9542
5.5	811	57	4.5825	0.7856	5.8329
6.1	1242	12	0.5099	0.1422	3.5850
6.2	3276	57	2.1776	0.3733	5.8329
6.3	1498	76	4.4309	0.7092	6.2479
6.4	208	29	3.6193	0.7450	4.8580
7.1	2095	60	4.0193	0.6840	5.9069
7.2	2237	38	2.1614	0.4119	5.2479
8.1	863	30	2.5193	0.5134	4.9069
8.2	1107	17	0.8126	0.1988	4.0875
8.3	3	1	0.0000	-	0.0000
8.4	396	30	3.8322	0.7810	4.9069
9.2	882	85	4.8566	0.7577	6.4094
9.3	123	5	0.9180	0.3954	2.3219
9.4	1181	67	4.1704	0.6875	6.0661

6.4.3. The individual installations

Farm 1

Farm 1 was located in a sheltered area between small and large islands (Fig. 3.1). Four stations were take here, three close to the installation and one outside the area (Station 1.3). The area around the farm was relatively shallow (less than 20 m) and the sediment consisted largely of sand (Table 6.1).

The farm started operating in 1973 with a volume of 3000 m³ and was expanded to 8000 m³ in 1976 (Table 3.5).

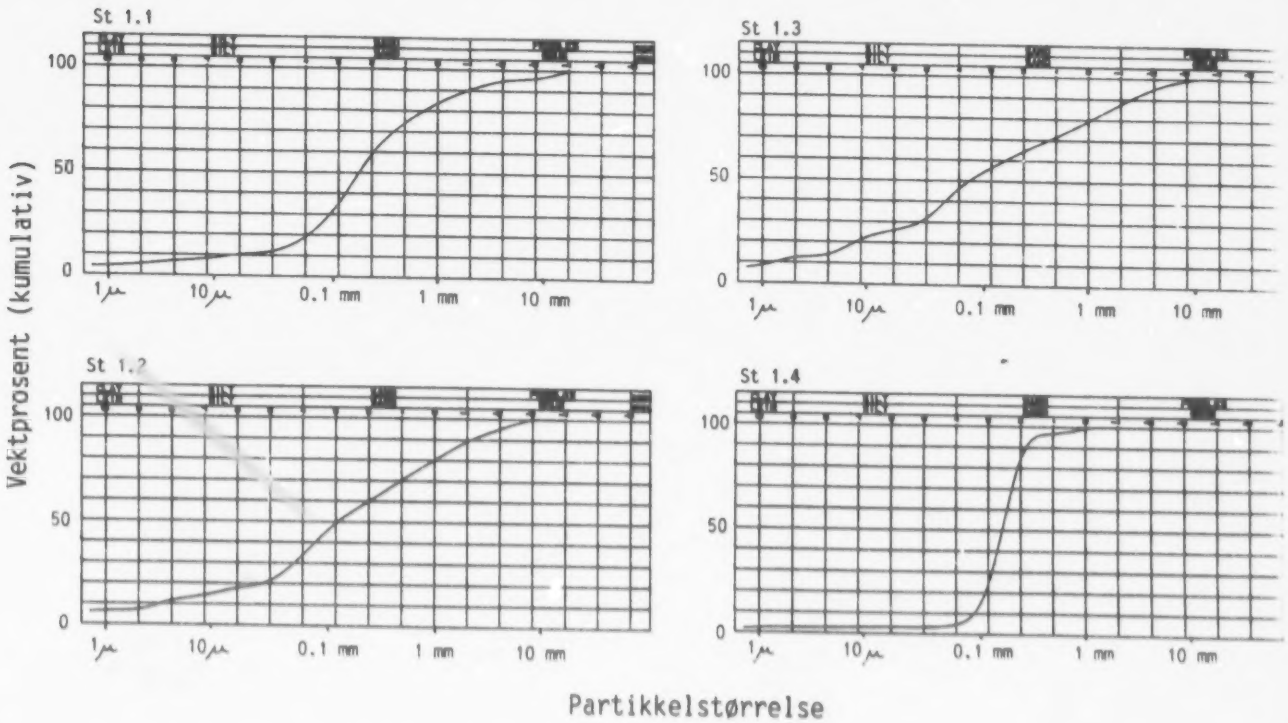

Fig. 6.2. Kornfordeling i sedimentet på stasjonene 1.1, 1.2, 1.3 og 1.4.

Grain size distribution in the sediment at station 1.1, 1.2, 1.3 and 1.4

Fig. 6.2.

Fig. 6.2 shows that Station 1.4 had clean sand, while the three others had very similar grain distribution with some silt and gravel. Table three shows that three of the stations had an ignition loss of from 6 to 10%, while Station 1.4 had a very low organic content with only 1.5% ignition loss.

At Station 1.1 a total of 53 species were found, 56 species at 1.2 and 58 at 1.3 (Table 6.3). At Station 1.4 the number of species was somewhat lower with 23 species.

Fig. 6.3 shows Table 6.3 presented in the form of a graph for the stations at Farm 1.

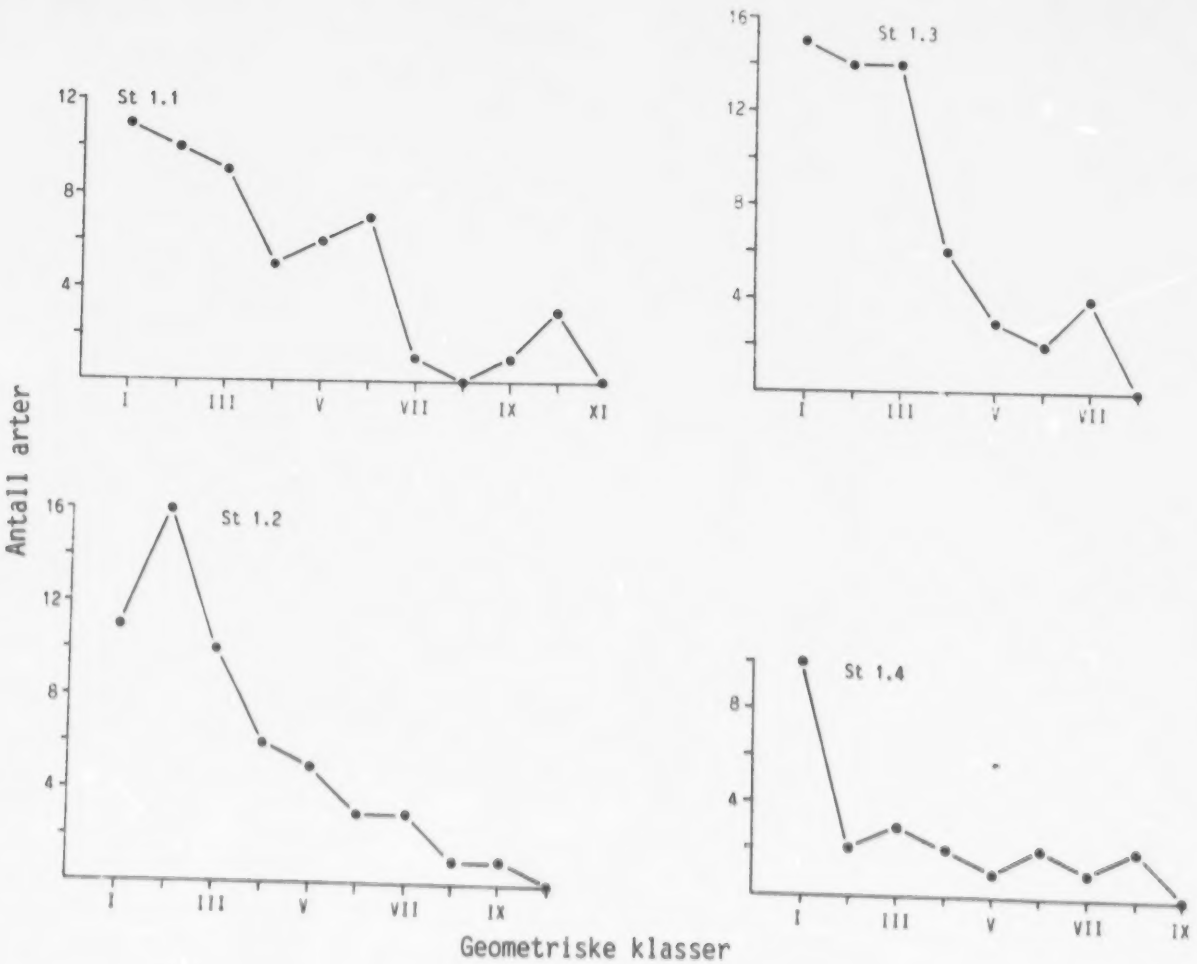

Fig. 6.3. Geometrisk klasse plottet mot antall arter for stasjonene 1.1, 1.2, 1.3 og 1.4.

Geometric class plotted against number of species at station 1.1, 1.2, 1.3 and 1.4.

The curves for Stations 1.1 and 1.3 show that these stations are somewhat affected by the installation since the curve has several tops. Geometric class X (which is a high class) has a clear top at Station 1.1. In Appendix 3 it can be seen that Class X at station 1.1 consisted of bristle worm species that are known to be able to survive in areas with organic loads (Spio filicornis, Polydora sp., Chaetosone setosa). Station 1.4 with relatively few species in two grab samples was more stressed than Station 1.1 (Fig. 6.3). Class VIII is here comprised by two species of bristle worms, Scoloplos armiger and Heteromastus filiformis. Scoloplos armiger was well represented at all four stations, but Heteromastus filiformis, that could also be found at all stations, has the decidedly highest number at Station 1.4.

The diversity (Table 6.4) was clearly lowest at Station 1.4 and highest at Station 1.3. This means that the diversity declined from unaffected areas in towards the installation. It must be emphasized that this is based on different numbers of grab samples. However, Stations 1.4 and 1.3 both had two samples so that these are directly comparable.

From this it must be concluded that the bottom fauna in the area closest to Farm 1 was affected by organic stress (loading) and was dominated by species that are known for being able to tolerate such stress.

There were no sills of importance in the area of the farm, and the sediment conditions were relatively uniform. The area had a low supply of organic material and nutrient salts from other sources. This means that it was only the affect from the farm that resulted in the differences in the fauna composition at the stations.

Farm 2

The farm was located leewards of some small islets. The area also has a small sill out towards the fjord (Fig. 3.2). It started to operate in 1980 with a volume of 5000 m^3 (Table 3.5).

There was relatively little difference in depth between the three stations (18, 20 and 28 m, Table 6.1). The organic content of the sediment (Table 6.2) was low (5.2 to 7.5 % ignition loss), and the particle distribution was very similar at the three stations. At station 2.3 the sediment was still somewhat coarser than on the two other stations (Fig. 6.4). At stations 2.1 and 2.2 there was hydrogen sulfide in the sediment (Table 6.1).

The supply of organic material from other sources than the fish farm was negligible. This means that the fauna should be expected to be quite similar at all three stations assuming there were no fish farms in the area.

Table 6.3 shows that Station 2.2 had a very high number of species and of individuals, while at Station 2.1 the number of species was very low and the number of individuals high. This difference is clear even if 5 grab samples were taken at 2.2 and only 2 samples at 2.1. Station 2.3 had a high number of species and individuals. The curve in Fig. 6.5 shows that Station 2.1, that is located closest to the farm, differ clearly from the others. It is a separate top on geometric class X. The species Malacoceros fuliginosa and Capitella capitata comprise this class (see Appendix 3). Here it is especially C. capitata that is known to occur in large numbers in areas with high organic loads. Another feature at Station 2.1 was that almost all molluscs had disappeared. The diversity at Station 2.1 (Table 6.4) was low. At Station 2.2 there was possibly a stimulation of the fauna in that both the numbers of species and individuals were high. This means that the fauna close to the farm showed clear signs of organic loading (stress). In a relatively short distance from the farm, the fauna was ,however, stimulated by the organic material.

Fig. 6.4. (p.65)

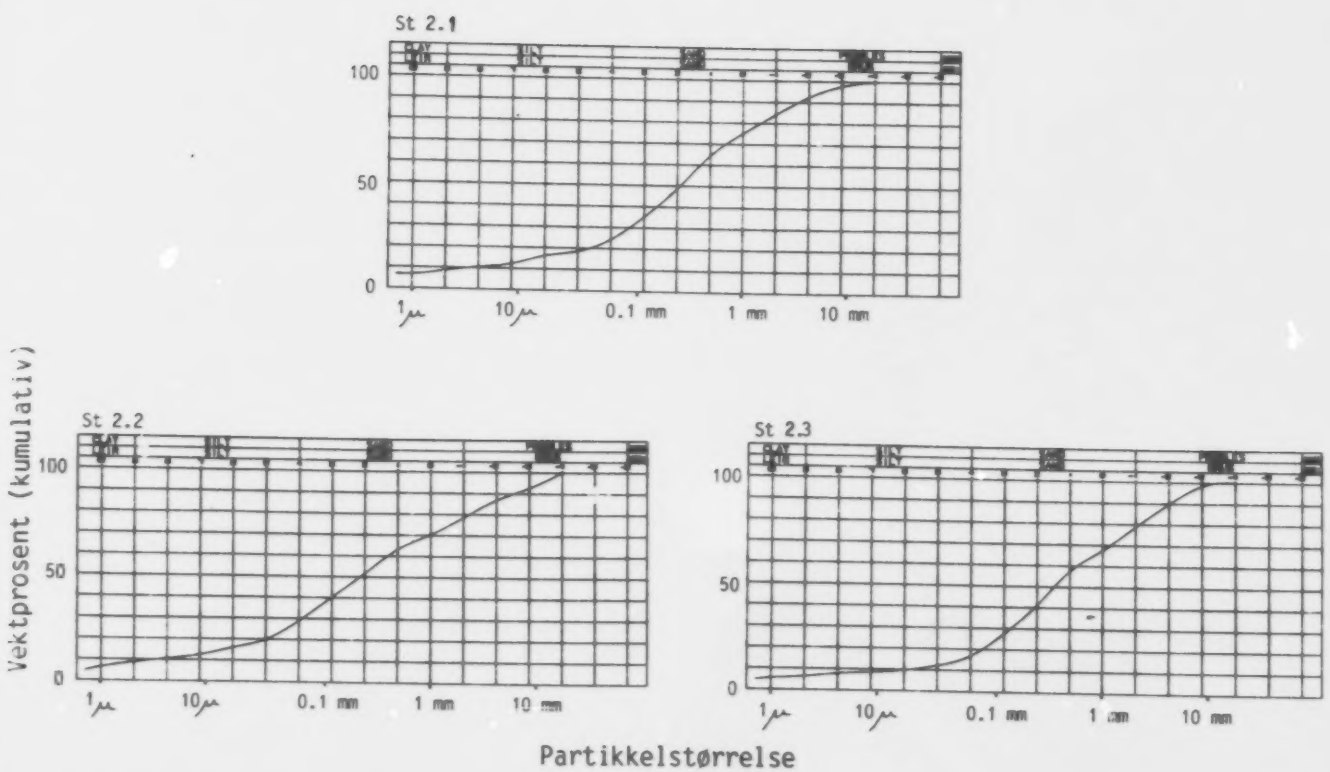

Fig. 6.4. Kornfordeling i sedimentet på stasjonene 2.1, 2.2 og 2.3 på anlegg 2.

Grain size distribution in sediment at station 2.1, 2.2, 2.3, for fish farm 2.

Fig. 6.5.

(p.66)

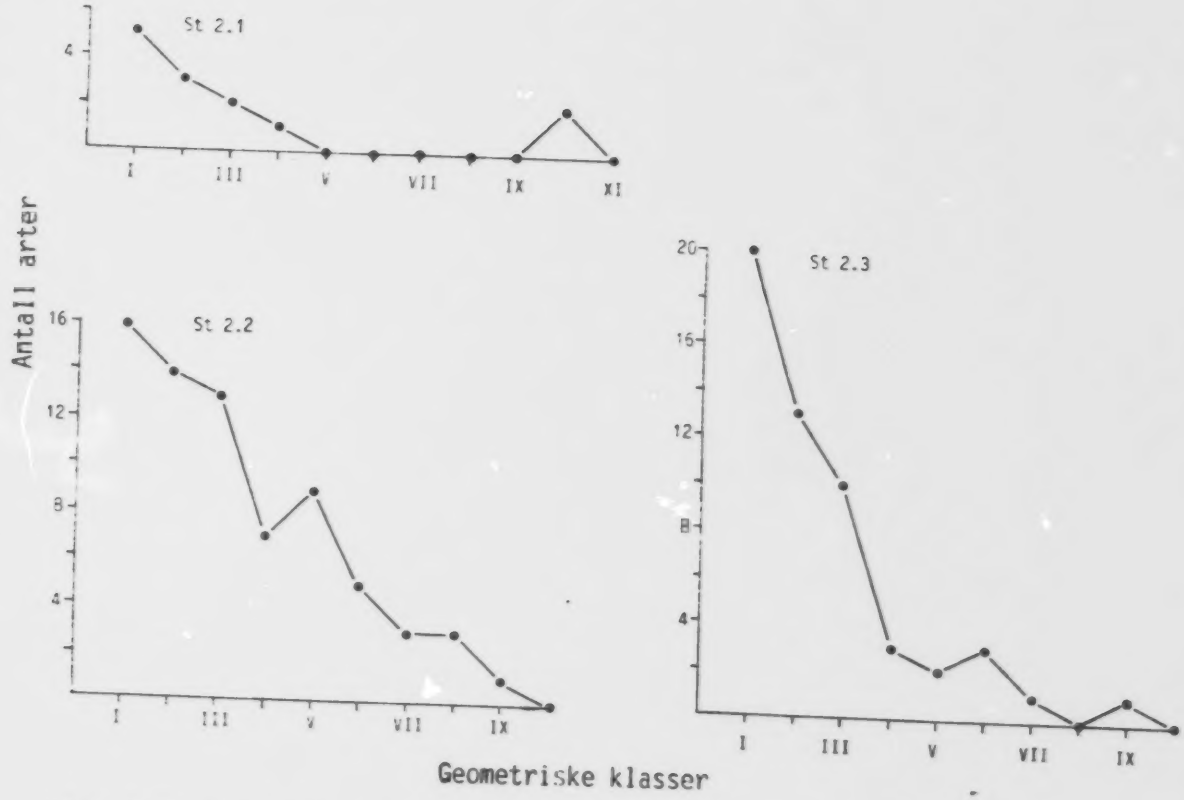

Fig. 6.5. Geometrisk klasse plottet mot antall arter for stasjonene 2.1, 2.2 og 2.3.

Geometric class plotted against number of species at station 2.1, 2.2 and 2.3.

Farm 3

The farm is located in a deep basin with shallow sills (Fig. 3.3). Four stations were taken in the basin towards the fish farm. In addition, two samples were taken at two stations in a basin outside where the farm operator would like to move some of his installations.

The farm was in operation already in 1973 with a volume of 3000 m^3. This volume was in 1978 expanded to 8000 m^3. In 1980 it was expanded further to 13,000 m^3 (Table 3.5).

Station 3 was located in the inner basin at 25 m depth near the farm (Table 6.1). The three other stations were placed in the deepest part ; Station 3.3 closest to the farm. The three deep stations had a uniform sediment with extremely high organic content, ca 40% loss on ignition (Table 6.2).

The sediment was fine grained, mostly silt and clay (Fig. 6.6), and it had an odor of hydrogen sulfide (Table 6.1).

Of the two stations in the outer basin (Fig. 3.3), Station 3.6 was placed in the deepest part (86 m) and Station 3.5 somewhat shallower. Station 3.5 had a sediment that chiefly consisted of sand with a low organic content (4.7% loss on ignition). At station 3.6 the sediment was fine grained (silt and clay), and the organic content was high (ca 36% ignition loss).

Station 3.1 was the only one that had a high number of species here (Table 6.3). The benthos was rich and indicate good conditions (Fig. 6.7).

Station 3.5 had fairly satisfactory conditions even if they by far were not as good as at Station 3.1. At the other stations the conditions were poor with a low number of species. The species distribution in Fig. 6.7 and the diversities (Table 6.4) show this quite clearly. The bristle worm Spiochaetopterus typicus (see Appendix 3) was the most numerous species at stations 3.2, 3.4 and 3.6 and forms respectively class X, IX and IX (?, IX listed twice. Transl. note) in Fig. 6.7. This is a species known to occur in large numbers in areas with high organic loading and stagnant basin water.

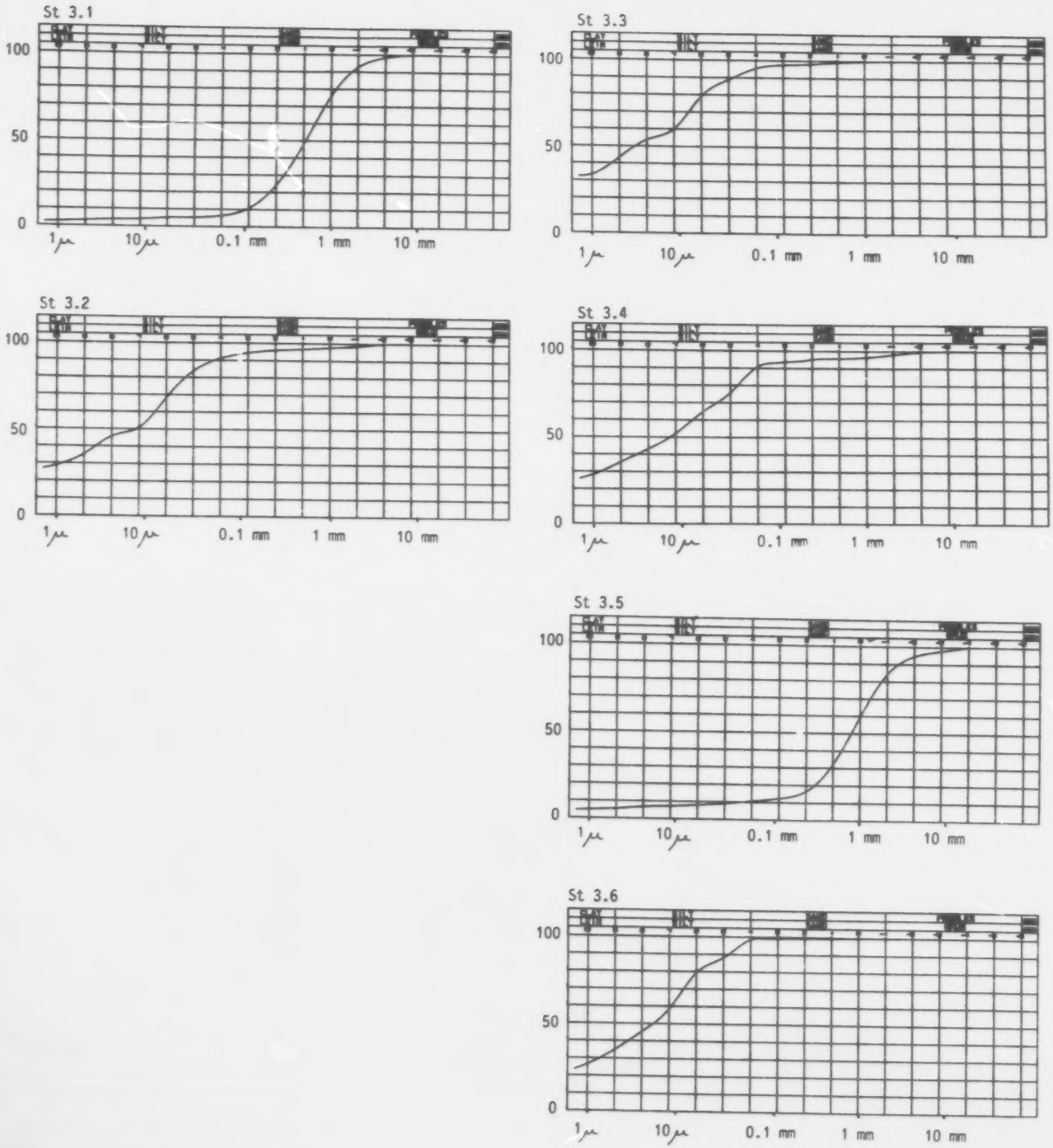

Fig. 6.6. Kornfordeling i sedimentet på stasjonene 3.1, 3.2, 3.3, 3.4, 3.5 og 3.6.

Grain size distribution in sediment at station 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6

In the deepest part of the basin there was little difference in the fauna between the stations, but a couple of details could be worth mentioning.

Closest to the farm at Station 3.3, S. typicus was not as domineering as at Stations 3.2 and 3.4. At Station 3.3 there were no molluscs, but at Station 3.4 a few shells were found. At Station 3.2 there was a good stock of animals of the family Thyasira which is also known for occurring in sediments with a high organic content.

The effects of Farm 3 are closely associated with hydrographic and topographic conditions. Station 3.1 that is located on a plateau (25 m) near the farm, had good conditions. The oxygen conditions were good at this depth as shown in Sect. 3.2. Of the stations in the deeper parts of the basin, Station 3.3 located closest to the farm was most strongly affected. However, the basin has poor water exchange conditions and low oxygen values anyway (See 3.2).

The area outside, where the farm operator wanted to move his farm , also has poor conditions in the deep parts.

Farm 4

This farm was investigated outside the original program. The collection of samples was therefore not as good as in the other farms.

The farm was located in a sill area (ca 20 m) with a basin with depths over 40 m on one side and an open fjord area on the other. The farm started to operate in 1978 with a volume of 3500 m^3 and was expanded in 1983 to 8000 m^3 and then to 10800 m^3 in 1984. The farm is an experimental installation with low production.

Four stations were sampled at this farm (Fig. 3.4). One station (4.1) was taken in the basin where the sediment was black, contained hydrogen sulfide and had no animal life

(Table 6.1). The organic content in the sediment was high (31%

Fig. 6.7

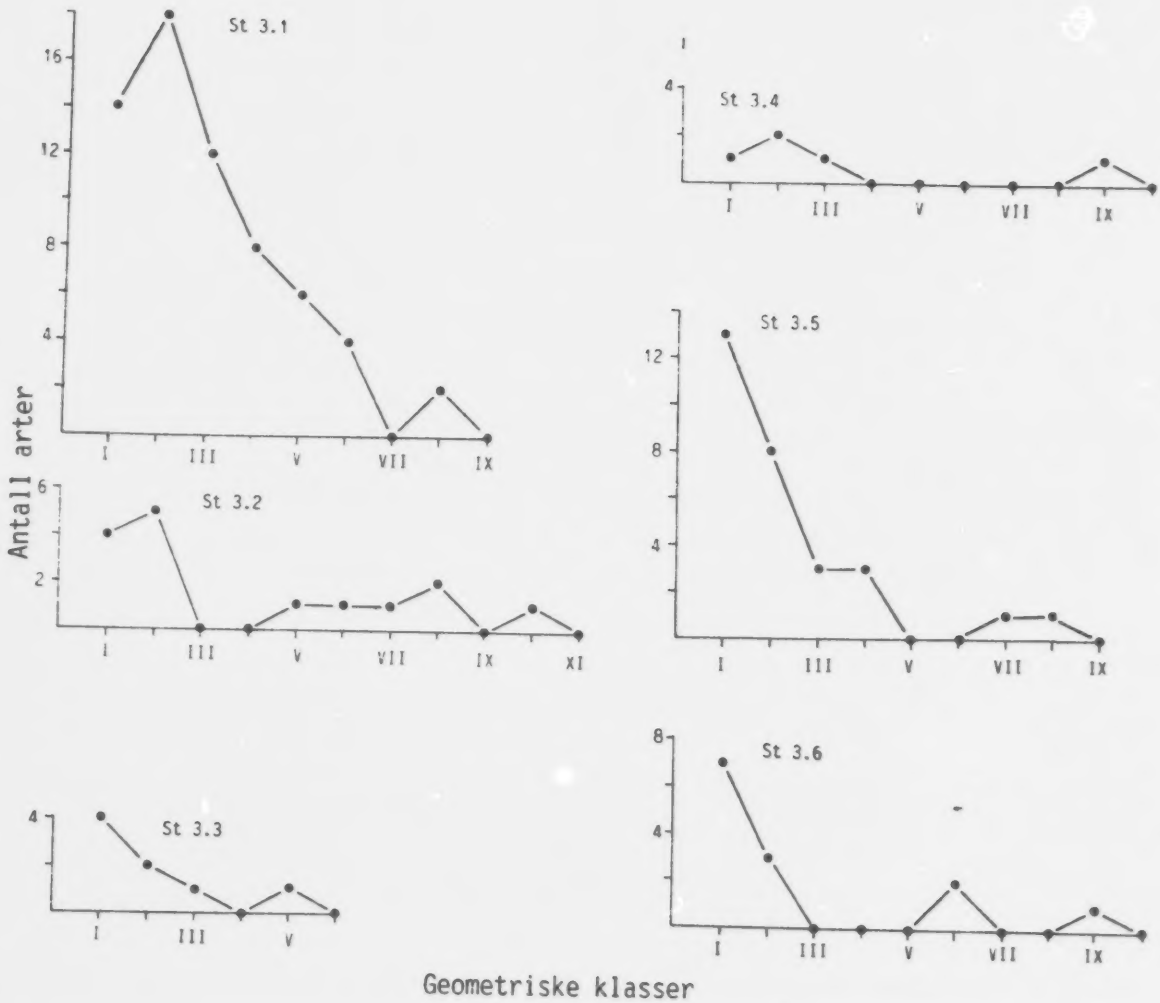

Fig. 6.7. Geometrisk klasse plottet mot antall arter for stasjonene 3.1, 3.2, 3.3, 3.4, 3.5 og 3.6.

Geometric class plotted against number of species at station 3.1, 3.2, 3.3, 3.4, 3.5 and 3.6.

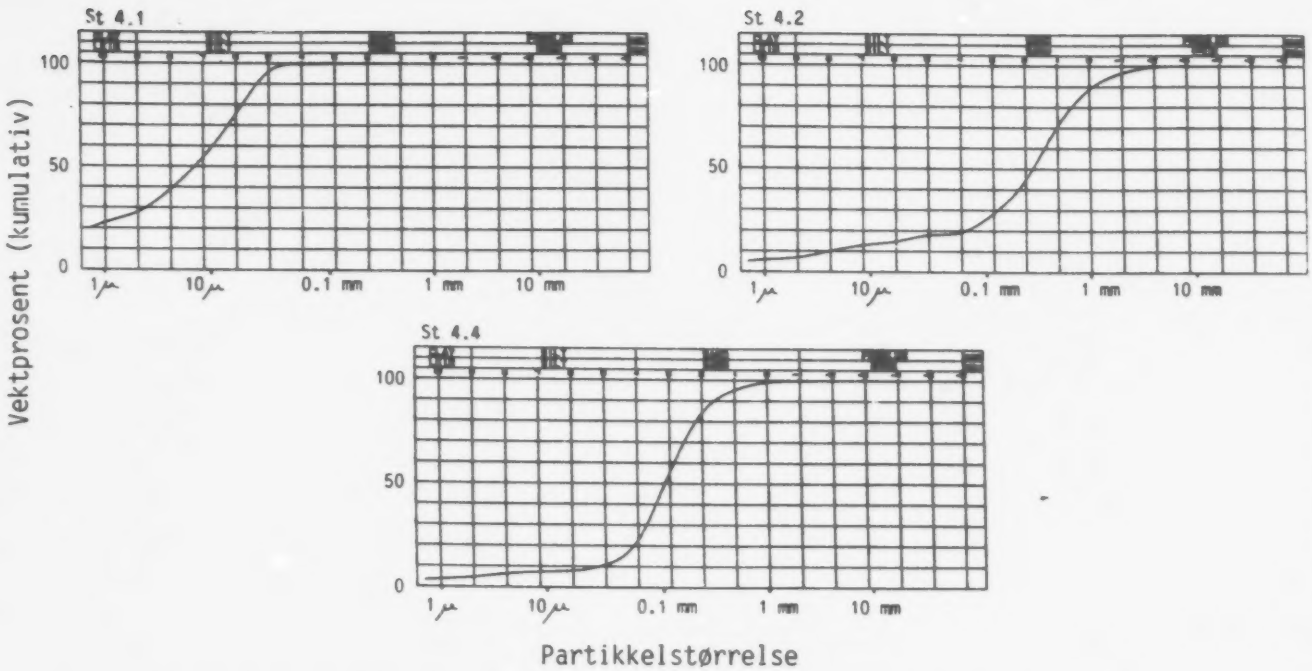

Fig. 6.8. Kornfordeling i sedimentet på stasjonene, 4.1, 4.2 og 4.4.

Grain size distribution in sediment at station 4.1, 4.2 and 4.4.

loss on ignition), see Table 6.2. The sediment was very fine grained and consisted of clay and silt (Fig. 6.8).

Another station (4.3) was attempted in an area with only hard bottom and where it was impossible to get samples with the grab (bedrock, see Table 6.1).

One of the reasons for the poor conditions at Station 4.1 is that the area is enclosed by sills. This area receives in addition some sewage and runoff and release from agriculture and smolt producing plants (See Table 3.5).

At Stations 4.2 and 4.4 the bottom consisted of sand (Fig.6.8) with a low organic content (Table 6.2). The benthic fauna at these two stations was rich with a high number of

species (Table 6.3) and normal species composition. The curves in Fig. 6.9 show that these two stations had no pollutant load. The diversity was high (Table 6.4). It must be emphasized that these evaluations were made on the basis of one grab sample at each station. One sample is generally not enough to make definite conclusions, but in this case the results were so unambiguous that we are sure that the conclusion is correct.

No effect of the farm can be demonstrated from the collected material. The results agree with a study done by OLSGARD (1984).

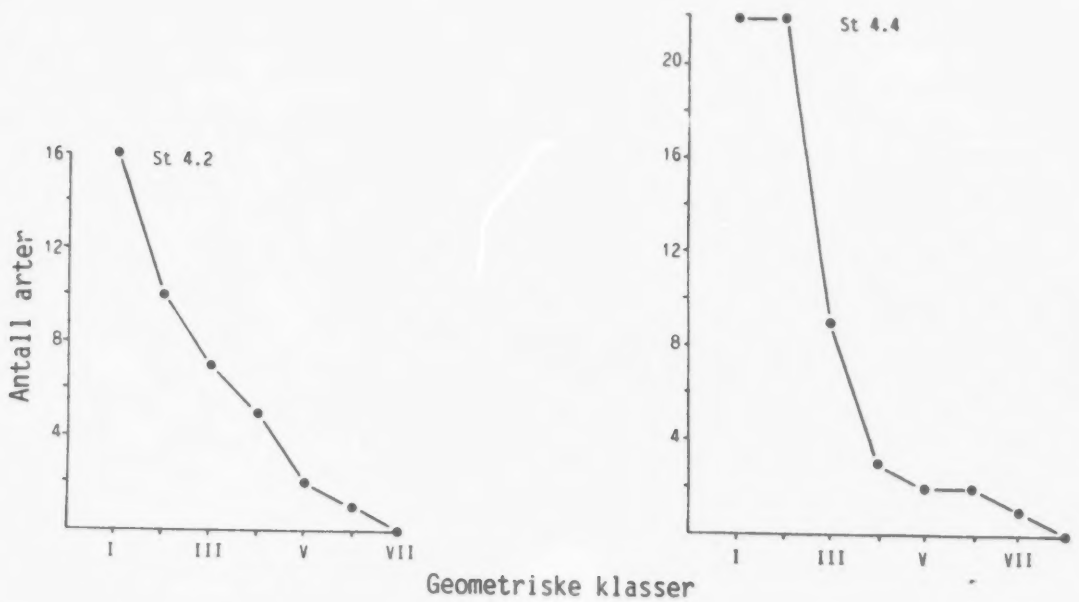

Fig. 6.9. Geometrisk klasse plottet mot antall arter for stasjonene 4.2 og 4.4.

Geometric class plotted against number of species at station 4.2 and 4.4.

Fig. 6.9.

Farm 5

The farm is located on the inside of several islets, and the shallow and in part narrow sounds with deeper basins in between results in a relatively enclosed area (Fig. 3.5). The farm started operating in 1980 with a volume of 15,000 m^3, and it has had the same volume since the study was undertaken (Table 3.5). This is a large fish farm.

The installations have been moved around within the area, and it has been located both at Stations 5.2 and 5.5. There is a deeper basin on the inside of the islets with a maximum depth of 24 m with naturally occurring poor oxygen conditions in the bottom water. The area between the islets out towards the more open fjord is relatively shallow. At this farm and the area around, it was found that conditions were very variable and six stations were therefore taken here (see Table 6.1).

No animal life was found at as many as three of the (p.72) stations (5.1, 5.2 and 5.5). Based on observations of the sediment it is obvious that the poor conditions at Stations 5.2 and 5.5 were due to the fish farm. At Station 5.2 the sediment consisted of a black, foul smelling top layer, and under this there were shell sand with large empty shells. The organic content is 7.7% (See Table 5.2). At Station 5.5 the sediment was liquid and without firm structure; organic content 35% (Table 5.2). At station 5.1 it was not possible to see any direct effect of the farm. The organic content at Station 5.1 was very high, as much as 49% (Table 6.2). Fig. 6.10 shows that Stations 5.1 and 5.5 had a fine-grained sediment that chiefly consisted of silt and clay. At Station 5.2, which was also without animal life, the sediment was much coarser and consisted chiefly of sand and gravel (Fig. 6.10). The organic content was normal (Table 6.2).

At the three stations with animal life, the sediments were relatively coarse with a high proportion of sand and gravel. The organic content was high at Station 5.3, while it was low at Stations 5.4 and 5.6 (Table 6.2)

The animal life at Station 5.3 was very poor, only four species with a total of 18 individuals were found in two grab samples. This station is heavily contaminated (loaded) from the fish farm.

Station 5.4 was also clearly affected by the farm, as seen in the curve for the station in Fig 6.11. The number of species was fairly high at this station, but a couple of species had very many individuals. Geometric class XII, which is very high for three grab samples, was formed by the bristle worm Capitella capitata (see Appendix 3). The very high number of individuals gives in this case also low diversity (Table 6.4). C. capitata is, as earlier mentioned, a species that is known for occurring in large numbers in areas with heavy organic loads.

Large numbers of roundworms (nematoda, see Appendix 3), were also registered at this station. These are not included in the analysis since they were not collected quantitatively due to their small size. The nematodes are also known to occur in large numbers in areas heavily contaminated by organic materials. However, it is worth noting that the organic content in the sediment at Station 5.4 was not particularly high, only 5.6% loss on ignition.

At Station 5.6 a natural benthic fauna was found (Fig. 6.11. and Appendix table 3) with a very high number of species. It is obvious that this station was outside the area affected by the fish farm.

Farm 5 was the farm that in this study had clearly most affected the environment. This is due to both the size of the farm and the location in a shallow area with deep basins, sills and island that hindered good circulation.

Fig. 6.10. (p.73)

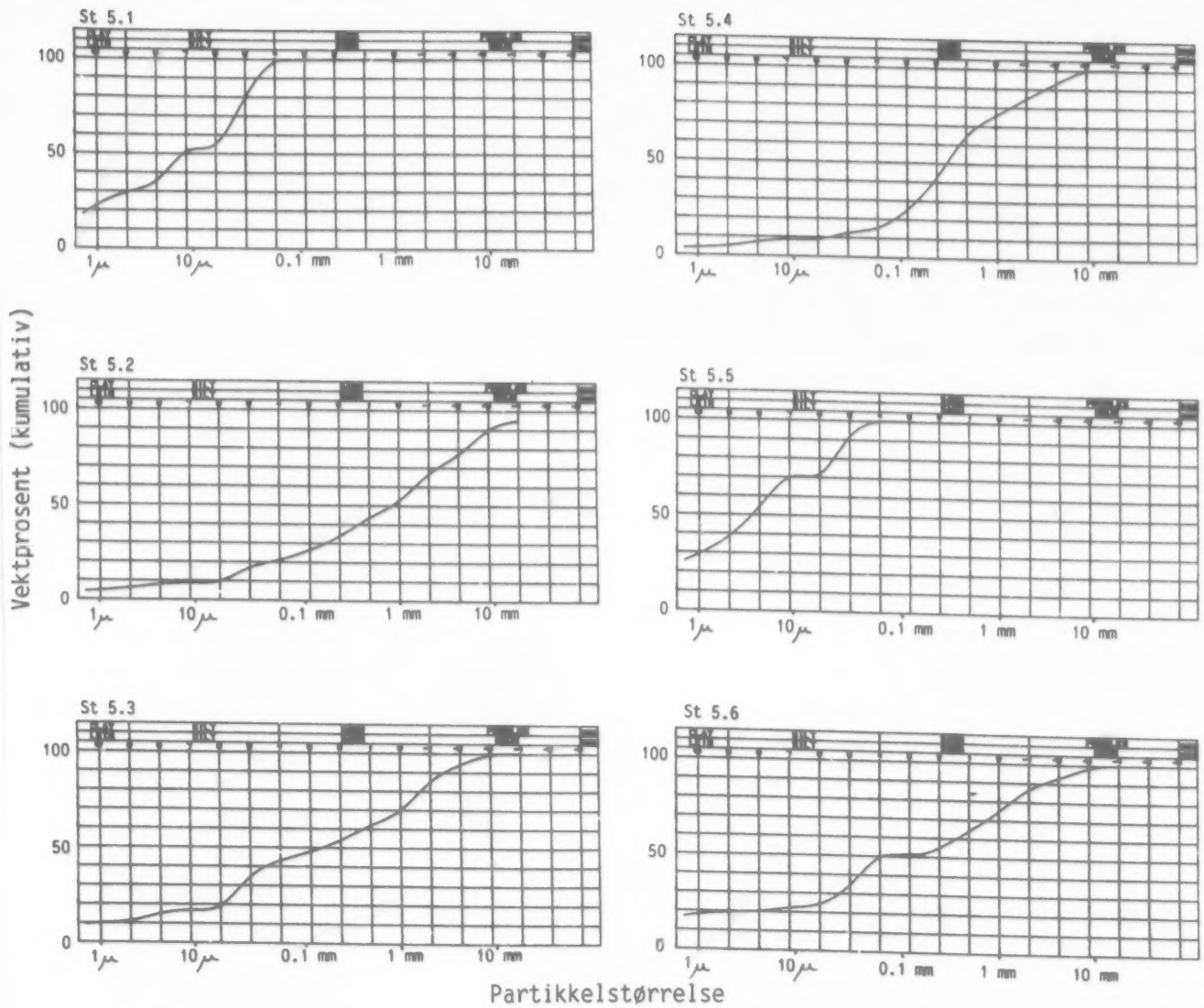

Fig. 6.10. Kornfordeling i sedimentet på stasjonene 5.1, 5.2, 5.3, 5.4, 5.5 og 5.6.

Grain size distribution in sediment at station 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6.

Fig 6.11

(p.74)

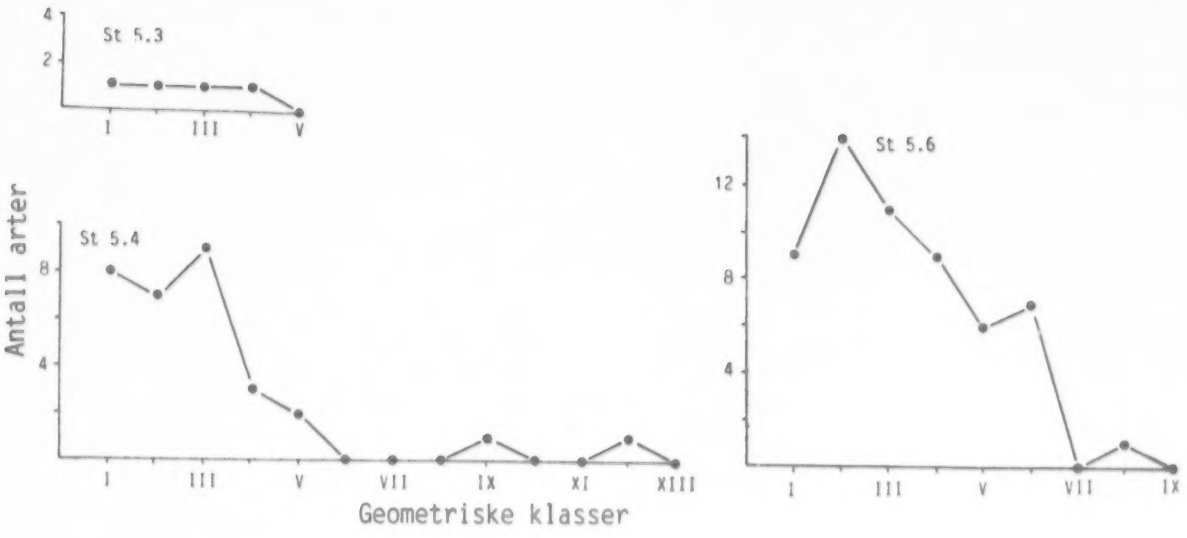

Fig. 6.11. Geometrisk klasse plottet mot antall arter for stasjonene 5.3, 5.4 og 5.6.

Geometric class plotted against number of species at station 5.3, 5.4 and 5.6.

Farm 6

This farm started operating in 1978 with a cage volume of 3000 m³ and was expanded to 8000 m³ in 1984. The farm is located in a sound between small and large islands with a deeper channel out towards open water. Four stations were placed in this channel (Fig. 3.6). All stations were relatively shallow. Station 6.4 was the deepest at 25 m (Table 6.1).

All four stations had a sediment that largely consisted of sand (Table 6.1, Fig. 6.12). The organic content was relatively low al all stations, and only at Station 6.2 was the ignition loss over 10% (11.2%, see Table 6.2).

This means that the natural conditions at these four

stations with respect to substrate should be quite similar, so that any effect of the farm should be easily observed. The station located closest to the farm (6.1) had only 12 species, but a high number of individuals (Table 6.3). This means again that the diversity at this station was very low (Table 6.4). The curve for Station 6.1 in Fig. 6.13 shows that this station was contaminated (loaded). The species that form Class XI is the bristle worm Capitella capitata. As earlier mentioned is this species known for being able to survive in areas with heavy organic loads(see Appendix 3).

Fig. 6.12 (p.75)

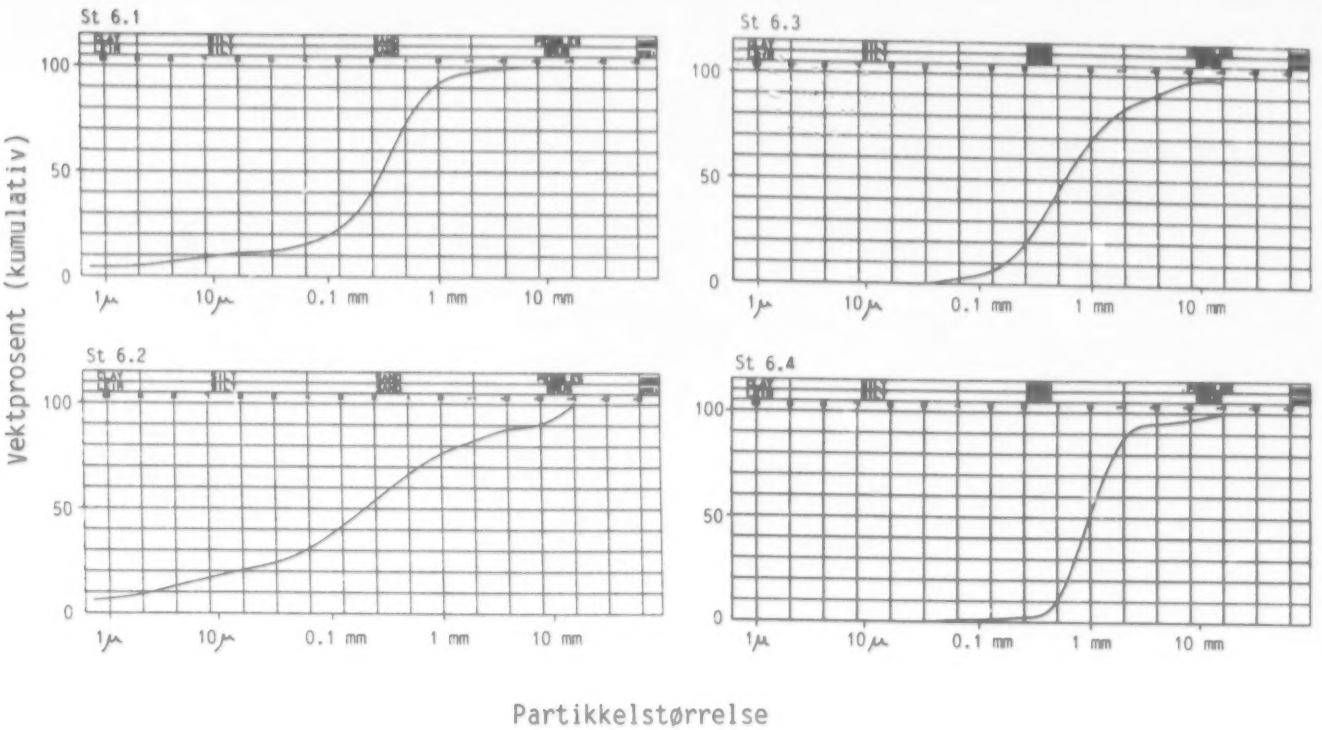

Fig. 6.12. Kornfordeling i sedimentet på stasjonene 6.1, 6.2, 6.3 og 6.4.

Grain size distribution in sediment at station 6.1, 6.2, 6.3 and 6.4.

Station 6.2 had a large number of species, but the curve in Fig. 6.13 shows that this station was mildly contaminated. The species that formed Geometric Class XII at this station was Chaetozone setosa which is a bristle worm that can tolerate moderate organic contamination.

At Station 6.3 the number of species was very high, as high as 76, and the curve in Fig. 6.13 shows that the conditions at this station were good. The diversity at this station is , as shown in Table 6.4, among the highest registered in this study. We assume that this is a station that was stimulated by the fish farm.

Only one grab sample was taken at Station 6.4 as a control of conditions outside the area of the fish farm. Three grab samples were taken at each of the other stations so these can not be directly compared with Station 6.4. However, there were no signs that Station 6.4 was affected by the fish farm.

Farm 6 had a definite effect on the benthic fauna in (p.77) the area. Since the outside conditions were so much alike, it was here possible to demonstrate a classic pattern for organic loading. Closest to the source (the farm), the number of species was low, and some species occurred in large numbers. The number of species and individuals increased a distance from the farm (Station 6.2), and a further distance away from the source, the number of species increased again while the number of individuals decreased. Further out (Station 6.4), there were areas with healthy and stable benthic fauna communities. It is worth noting that the distance from the farm to the area that had been stimulated is small.

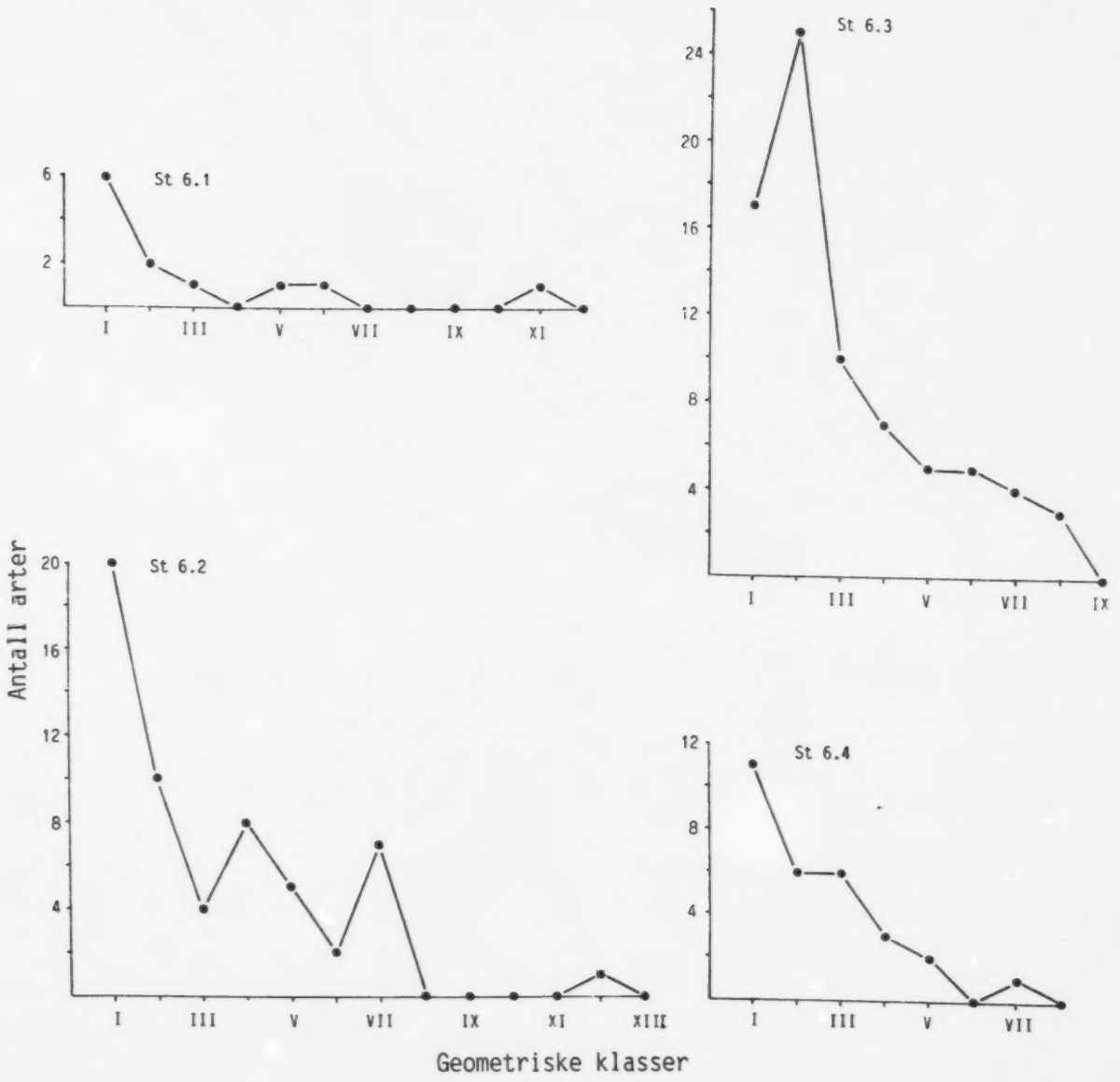

Fig. 6.13. Geometrisk klasse plottet mot antall arter for stasjonene 6.1, 6.2, 6.3 og 6.4.

Geometric class plotted against number of species at station 6.1, 6.2, 6.3 and 6.4.

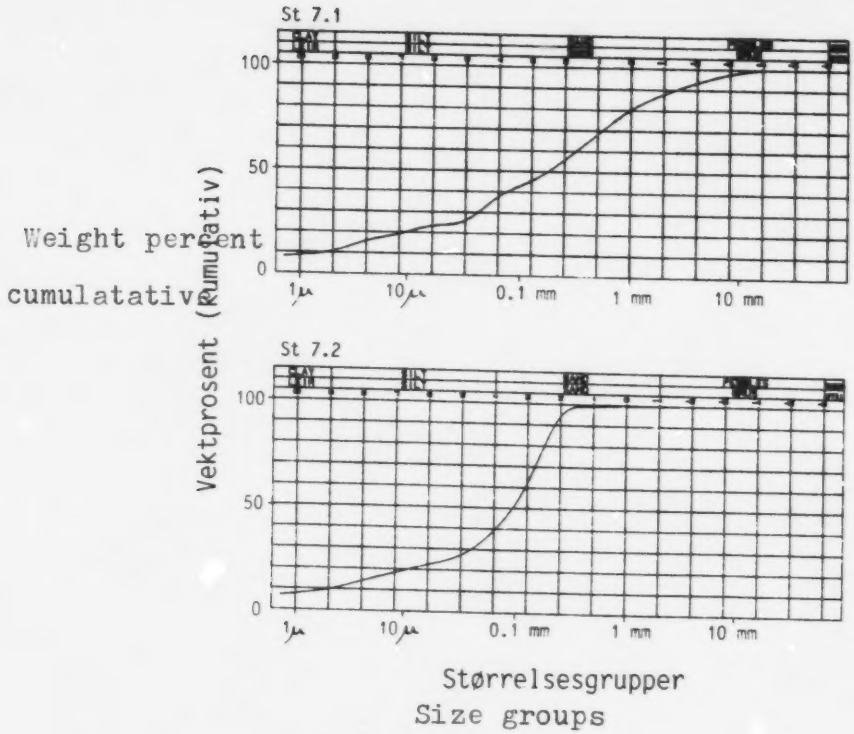

Fig. 6.14. Kornfordeling i sedimentet på stasjonene 7.1 og 7.2 på anlegg 7.

Grain size distribution in the sediment at station 7.1 and 7.2 at fish farm 7.

Farm 7

Farm 7 was located in a bay in a relatively shallow area with many islets and reefs. The installation started to operate in 1972 with a cage volume of 5000 m³. It has been expanded twice since; in 1980 to 13,000 m³ and in 1984 to 16,000 m³. Only two stations were take at this farm since it was located so near another farm (Farm 1) that they have one station in common (St. 1.3). Station 7.1 at 7.5 m depth was closest to the farm and Station 7.2 at 25 m depth was located in a small basin somewhat further away (Fig. 3.1 and Table 6.1).

Station 7.1 had a mixed coarse sediment (Fig. 6.14), while the sediment at Station 7.2 consisted of more pure sand. The

organic content was approximately the same at the two stations; ca 9% loss on ignition (Table 6.2).

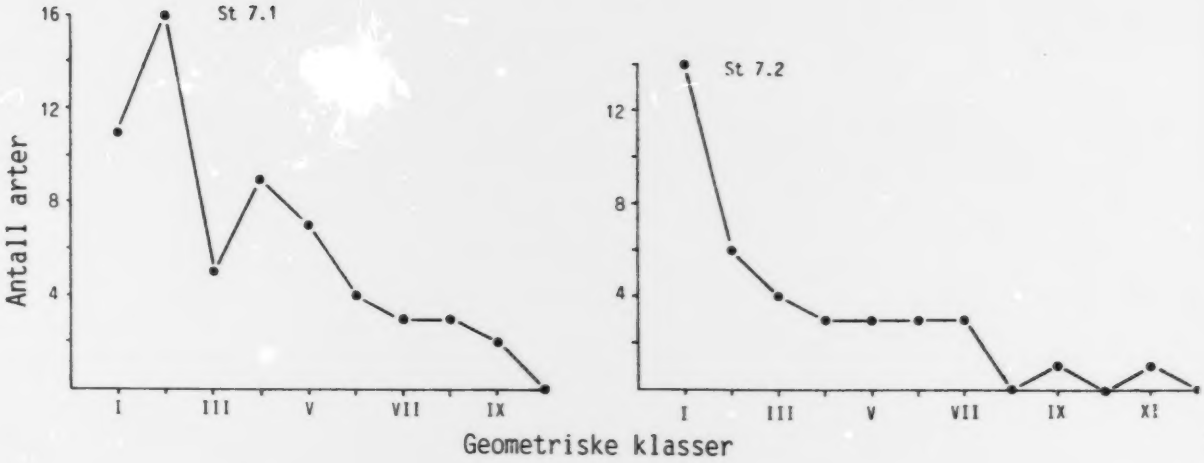

Fig. 6.15. Geometrisk klasse plottet mot antall arter for stasjonene 7.1 og 7.2.

Geometric class plotted against number of species at station 7.1 and 7.2.

The number of species was highest at Station 7.1 (60 species in 3 grab samples) and somewhat lower at Station 7.2 (38 species) while the number of individuals were relatively high at both stations (Table 6.3). This means that the diversity (Table 6.4) is high at Station 7.1 and low at Station 7.2. The curves in Fig. 6.15 show no clear signs of a pollution load- they rather indicate a weak stimulating effect. The species that comprises Class XI at Station 7.2 is Chaetozone setosa, and this has also been present in large numbers at other farms. With respect to Station 1.3 we refer to the comments under Farm 1.

This means that the stations studied do not show appreciable signs of being affected by the farm.

Farm 8

Farm 8 is located in a relatively open area (Fig.3.7), but deep sills form a basin in the area of the farm. A station was placed in the deepest part of this basin (8.3) at 40 m depth (Table 6.1). The other three stations were placed inward towards the farm. The area had inflows of organic material also from sources other than the farm. For example, sewage from ca 200 people and runoff from a slaughtering area for fish enters a nearby cove.

The farm started operating in 1980 with a cage volume of 5000 m^3. This was expanded to 7000 m^3 in 1984 and to 8000 m^3 in 1985.

The three stations 8.1, 8.2 and 8.4 all had a composite sediment where the largest part was sand (Fig. 6.16). At Station 8.3 the sediment was finer with a larger proportion of clay and silt, and here the organic content was higher (16.5% ignition loss) than at the three other stations (see Table 6.2). Station 8.4 had the lowest organic content with a loss on ignition of only 4.1%.

At Station 8.3 only one species was found, Capitella capitata with one individual in each of the three grab samples.

Few species were also found at Station 8.2 (17), but (p.80) the number of individuals was high. It was C. capitata that gave the large number of individuals (see Appendix 3). In Fig. 6.17. and Table 6.3 this species come in geometric class X, and the diversity was therefore low at this station (Table 6.4).

Some C. capitata were also found at Station 8.1, but here there were also other species with high numbers of individuals. The number (30) is considered to be below average , and the curve in Fig. 6.17. shows that also this station had a pollution load.

Station 8.4 which was closest to the farm, had the lowest pollution load. The diversity was here high and the curve in Fig. 6.17 does not show as clear signs of loading as for the three other stations.

Fig. 6.16.

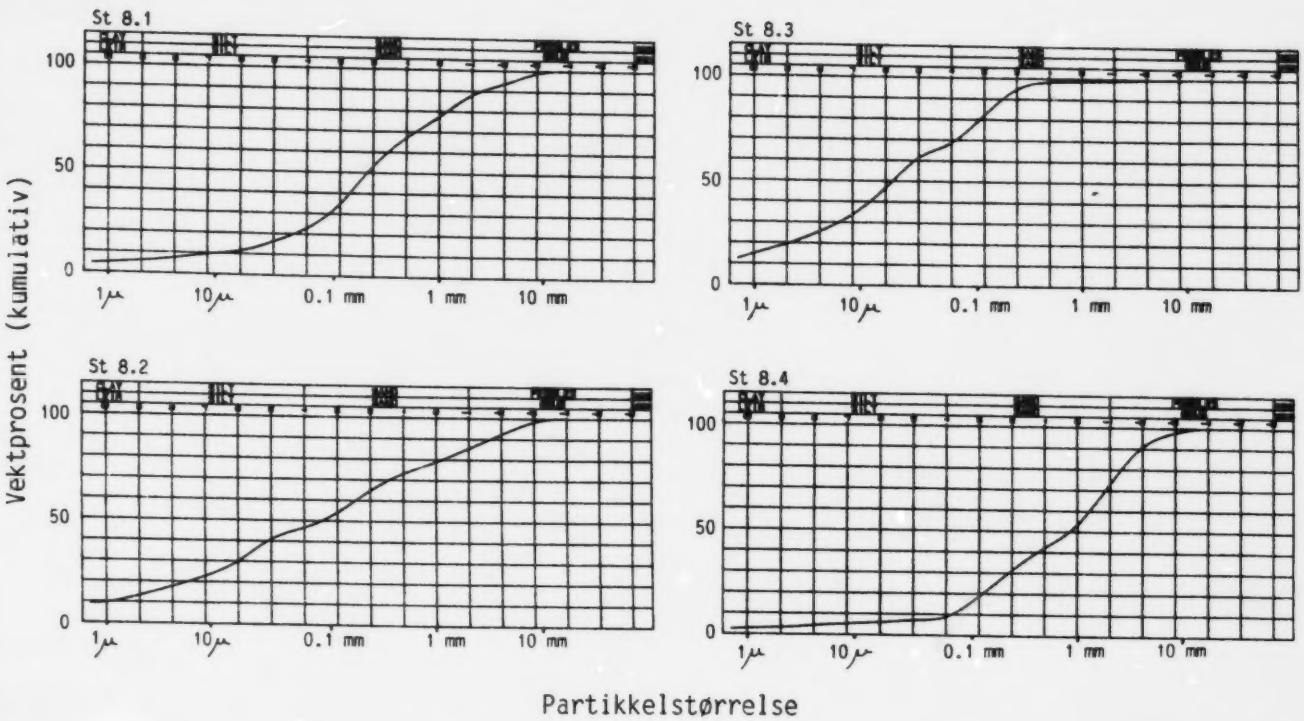

Fig. 6.16. Kornfordeling i sedimentet på stasjonene 8.1, 8.2, 8.3 og 8.4.

Grain size distribution in sediment at the station 8.1, 8.2, 8.3 and 8.4.

Fig.6.17.

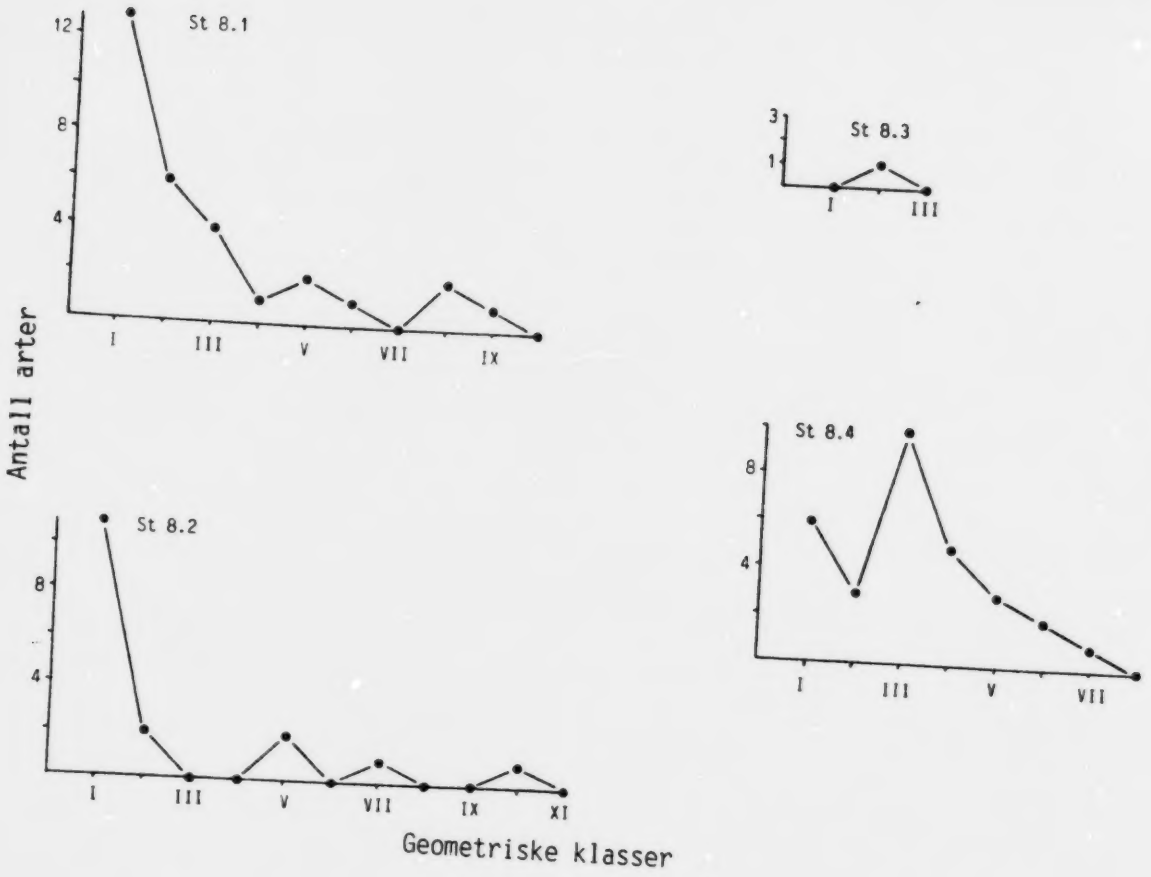

Fig. 6.17. Geometrisk klasse plottet mot antall arter for stasjonene 8.1, 8.2, 8.3 og 8.4.

Geometric class plotted against number of species at station 8.1, 8.2, 8.3 and 8.4.

It can appear as if the organic material was (p.81) transported down to deeper water, and this can be the reason for the effect at the deepest stations. It has happened that organic sediment was removed from the farm area by creating a current. The deep sills can in addition at times cause stagnant bottom water.

Farm 9

This installation is located in a relatively open area in a bay towards a larger basin with greatest depth 89 m and sill depth 30 m. A total of seven fish farms are located in this basin area. Just outside the sill is a sewage outlet for ca 680 people and process effluent from a fairly large fish processing plant. The farm studied started operating in 1979 with a cage volume of 5000 m^3. This was expanded to 8000 m^3 in 1984.

At the farm chosen in this area, samples were taken from three stations (Fig. 3.8). At the most shallow stations, Sta. 9.2 at 28 m depth (Table 6.1) and Sta. 9.4 at 45 m, the sediment had a low organic content (Table 6.2), and the sediments were relatively coarse and consisted mostly of sand (Fig. 6.18).

At the deepest station, 9.3 (85 m), the sediment was more fine grained, clay and silt, and the organic content was high with 21.6% ignition loss.

The number of species found at stations 9.2 and 9.4 was very high, especially at station 9.2 with 85 species (Table 6.3). This station had the largest diversity of the whole study (Table 6.4). The curves in Fig. 6.19 do not exhibit any well defined peaks or high geometric classes. The results can be interpreted such that Stations 9.2 and 9.4 were stimulated by the fish farms.

However, Station 9.3 had a very poor fauna with only (p.83) five species, and all of these were bristle worms. The most plentiful of these was Spiochaetopterus typicus which here forms geometric class VII (Fig. 6.19).

As mentioned earlier, this species can occur in large

numbers in basins with naturally stagnant water.
Fig. 6.18.

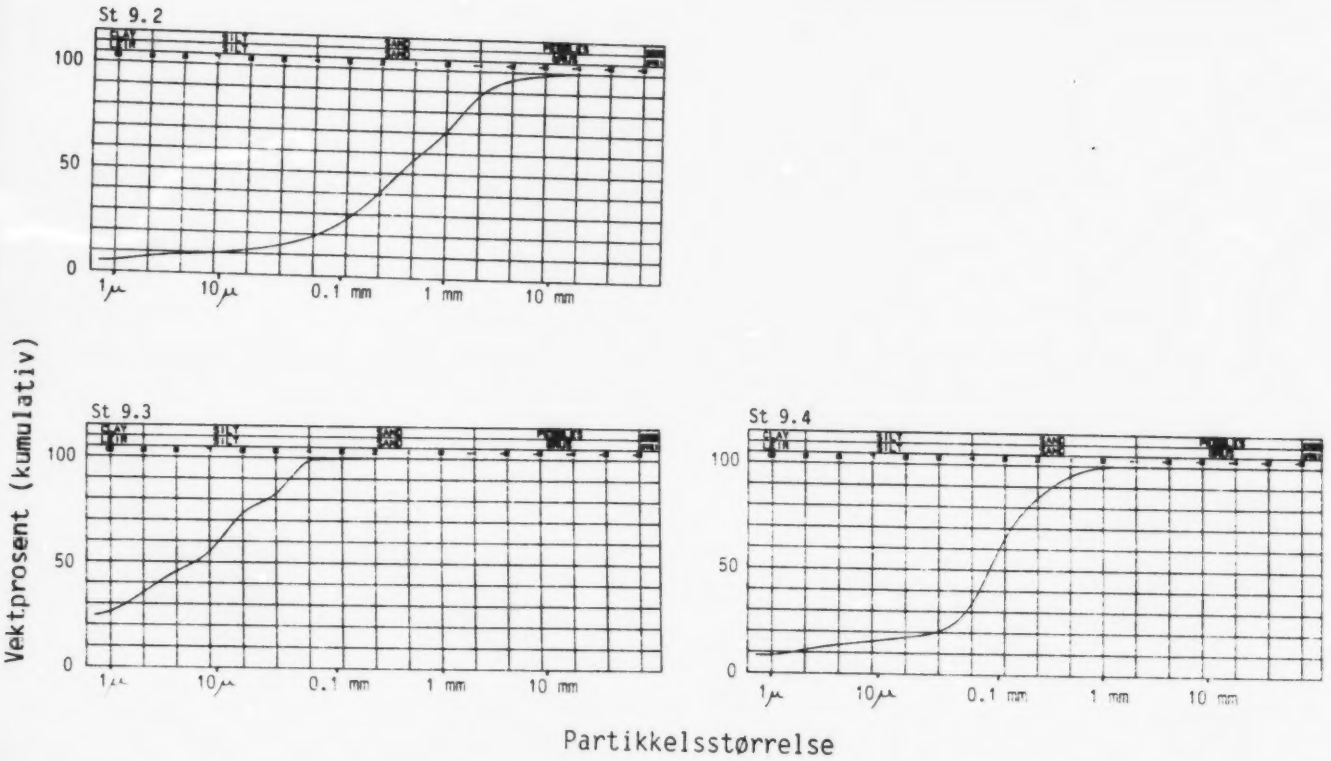

Fig. 6.18. Kornfordeling i sedimentet på stasjonene 9.2, 9.3 og 9.4.

Grain size distribution in sediment at station 9.2, 9.3 and 9.4.

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Fig. 6.19.

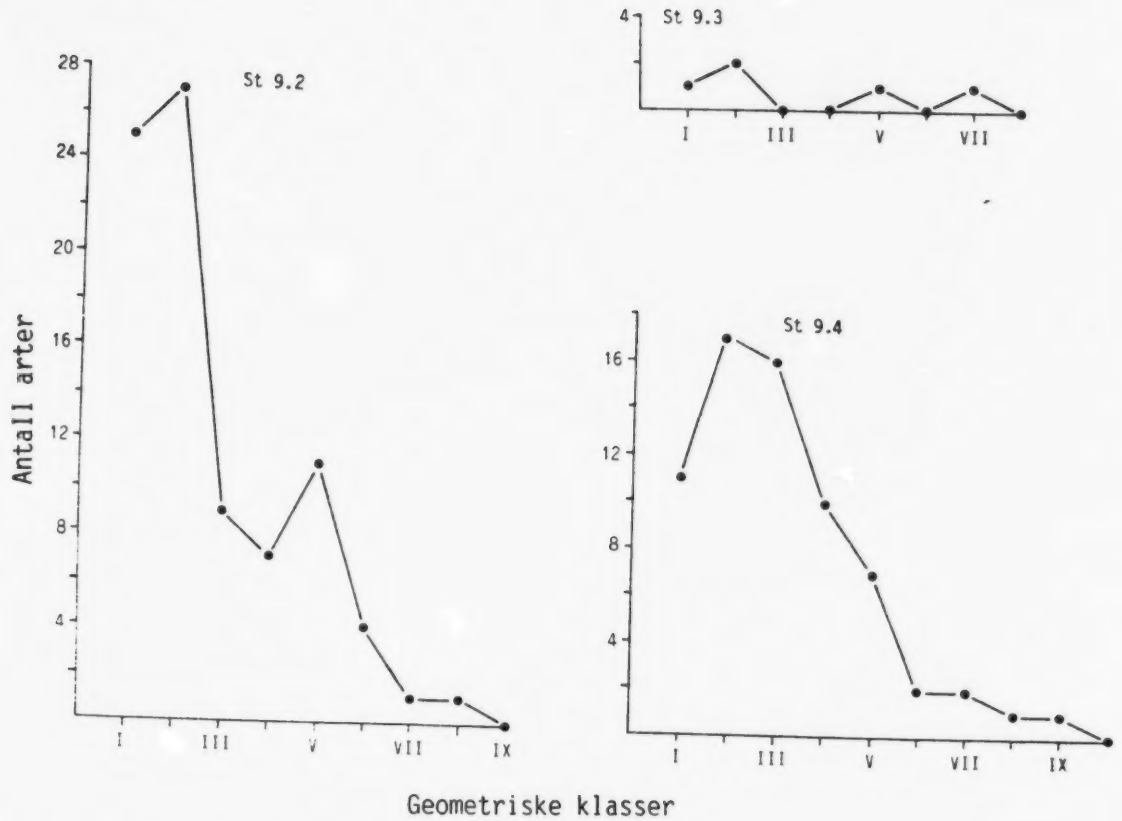


Fig. 6.19. Geometrisk klasse plottet mot antall arter for stasjonene 9.1, 9.2 og 9.3.

Geometric class plotted against number of species at station 9.1, 9.2 and 9.3.

6.4.4. Overall discussion

To investigate if there were general features common to the farms, or if there were north - south differences, a cluster analysis based on transformed and standardized data was performed (BRAY and CURTIS 1957; FIELD, CLARKE and WARWICK 1982). For further details see Appendix 3.

The cluster analysis resulted in the diagram shown in Fig. 6.20.

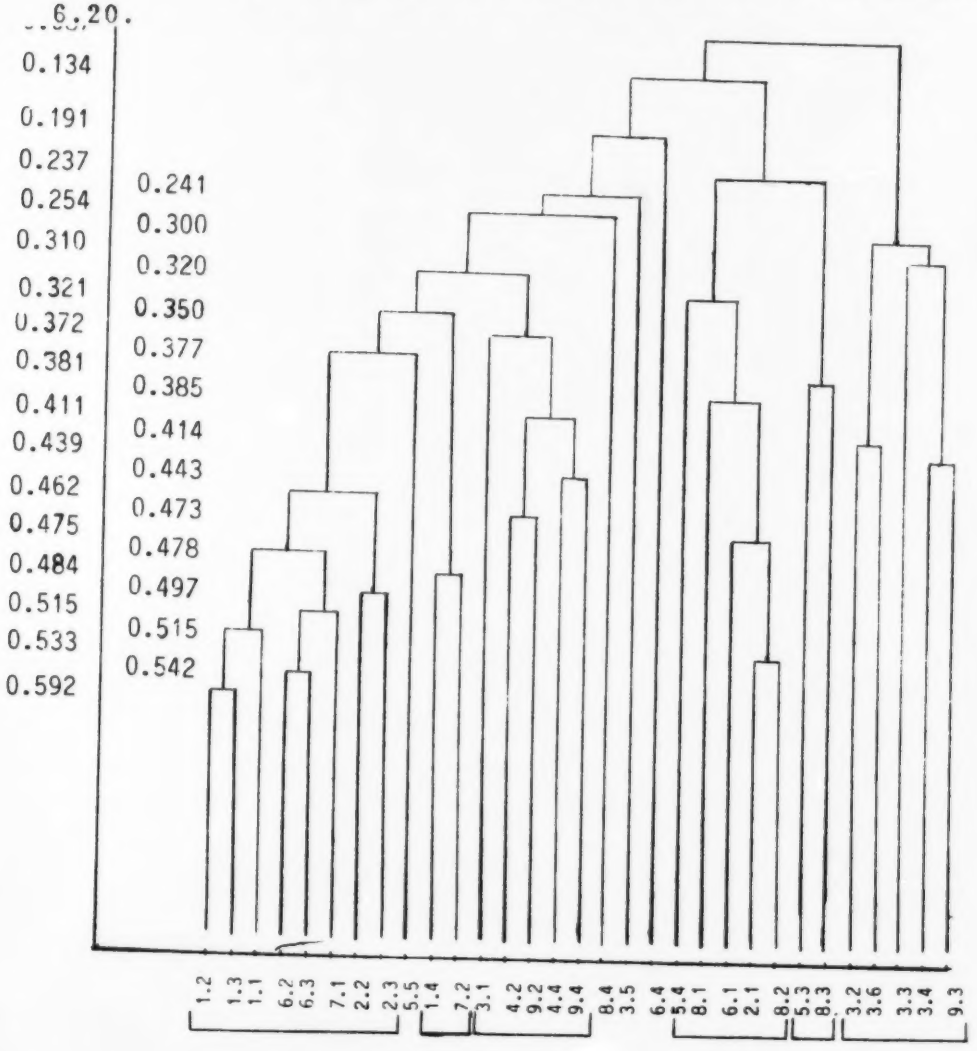


Fig. 6.20. Dendrogrammet viser klassifiseringen av 31 stasjoner ved de ni undersøkte oppdrettsanleggene. Stasjonsgrupperinger er markert med klammer.

Classification of the 31 stations distributed over the 9 fish farms investigated. Clustering is illustrated by brackets.

The bar graph in Fig. 6.20 shows a confused situation, and resemblance between stations is low. There are some groupings such as Stations 5.3 and 8.3, Stations 3.2, 3.6, 3.3, 3.4 and 9.3 and Stations 9.4, 4.4, 9.2, 4.2 and 3.1. If we look at the species distribution in the three mentioned groupings, the first has very few species (4 and 1), the middle group has few (from 5 to 15), and the last in part many species (41 to 85).

This result could, however, easily have been reached without doing complicated analyses. In other words it means that it was not possible from the cluster analysis to conclude more about similarities and differences in the material than what could relatively easily be extracted from the raw material.

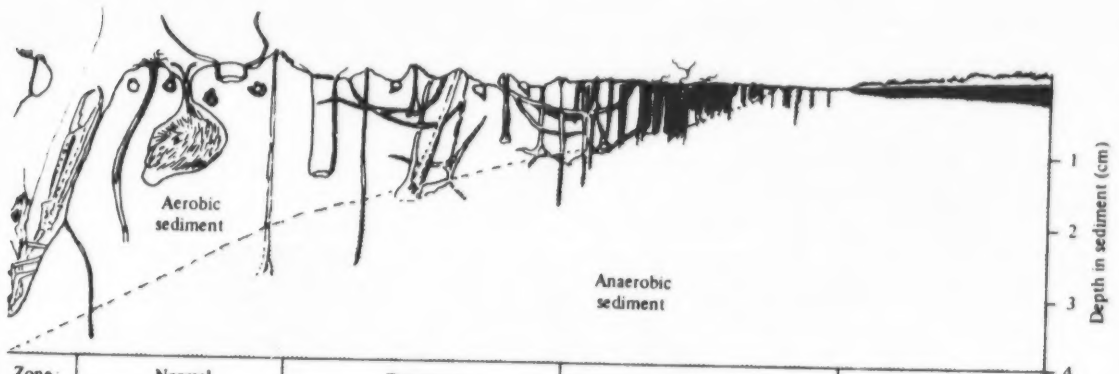
The consequence of this is that each farm must be treated and evaluated separately. External conditions such as topography, hydrography, currents, supplies from shore, size of the farm and feeding routines all contribute to give special conditions at each installation. Each aquacultural locality must therefore be treated individually.

PEARSON and ROSENBERG (1978) have given an extensive review over the problems of organic pollution, and their classical outline of how conditions are affected by organic pollution is shown in Fig. 6.21.

At some of the installations the stations covered the whole spectrum from polluted to unaffected. This is seen most clearly at Farms 2 and 6 where the stations have approximately the same depths, sediment type and hydrographic conditions. The same pattern was found by BROWN, GOWEN and McLUSKY (1987) in farms in Scotland.

At other installations the pattern can be more complicated, and effects are first and foremost determined by currents, hydrography and topography, and to a lesser degree by the distance from the farms. Examples of this are Farms 3 and 6 where the deeper parts of the basins were polluted while the stations near the farms were stimulated.

At Farm 5 the effects of the shallow and enclosed area are so massive that most of the stations were located in the strongly affected area (Fig. 6.21). It should still be noted that St. 5.6 that is located 500 m from this farm was unaffected.



Zone:	Normal	Transitory		Polluted	Grossly polluted
Typical macrofauna dominants:	*Nucula* *Amphiura* *Terebellides* *Rhodine* *Echinocardium* *Nephrops*	*Labidoplax* *Corbula* *Goniada* *Thyasira* *Pholoe*	*Chaetozone* *Anaitides* *Pectinaria* *Myriochele* *Ophiodromus*	*Capitella* *Scolelepis*	No macrofauna: surface covered by fibre 'blanket'

Fig. 6.21. Forandring i fauna og sediment langs en gradient med organisk belastning (PEARSON and ROSENBERG 1978).

Fauna and sediment changes along a gradient of increasing organic loading (PEARSON and ROSENBERG 1978).

High organic content in the sediment is not always coupled to an impoverished fauna and vice versa. Examples are Station 2.1 at Farm 2 and station 6.1 at Farm 6 that both had a low organic content in the sediment at the same time as the fauna was very poor and the area showed signs of having a high organic loading.

The current study shows that the benthic fauna gives a clear indication of if areas around fish farms are affected or not, and we recommend benthic fauna investigations together with information on the sediment for evaluating fish farm installations.

6.4.5 Littoral zone studies

The littoral zone was inspected at all installations. In addition ,registration of plants and animals in the littoral zone was carried out at Farms 2 and 9. This registration was performed in cooperation with cand. scient. Kjell Emil Naas. He prepared a short report which is used as basis for this section.

Farm 2.

A profile of the large algae and animals in the littoral zone ca 20 m from the farm is shown in Fig. 6.22.

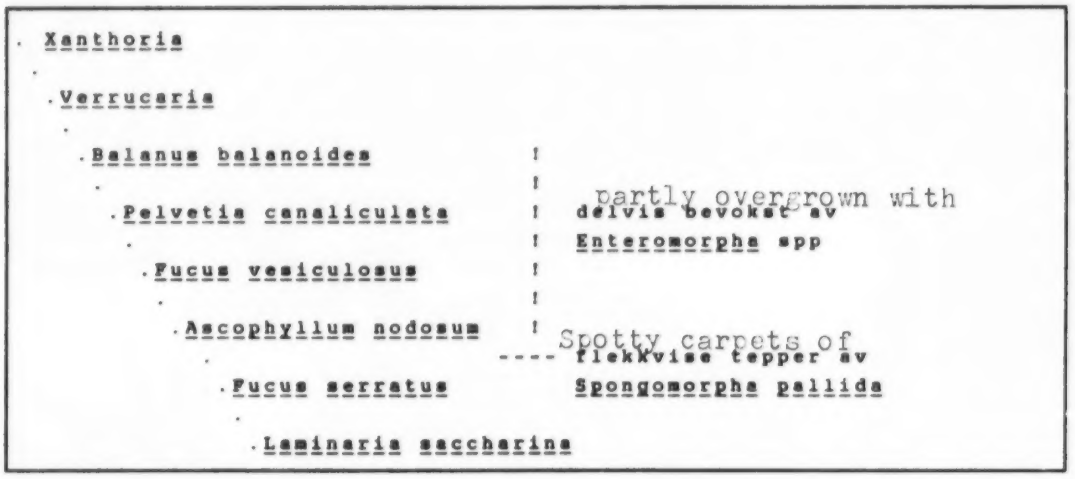


Fig. 6.22. Littoralprofil ca 20 m fra merdene ved anlegg 2.

Littoral profile approximately 20 m from the net pens at fish farm 2.

Fig.6.22

The anchoring ropes to the cages and the inside of the cages had a heavy growth of green algae of the families Chladophora and Enteromorpha, but there were also multiyear fucus sp. The sandy bottom in the littoral ca 30 m from the cages seemed to be completely unaffected. A striking feature was that the effect of the farm (extent of one-year old green algae) seemed to be of very local character.

Farm 9

The littoral profile ca 30 m from the cages at Farm 9 was roughly similar to the profile from Farm 2 (Fig. 6.20). Closer to the cages a larger number of threadlike green algae and brown algae on firm substrate was observed. The seaweed was more overgrown here than at Farm 2. The sandy bottom inside ca 10 m from the cages was in part covered by Ectocarpus. Ropes and cages were here somewhat less overgrown by one year old algae than in farm 2.

Discussion (p.87)

Both Farms 2 and 9 were relatively well protected. This is reflected in the algal community. Both rockweeds (A. nodosum, F. serratus) and kelp (L. saccharina) disappear after moderate exposure. Characteristic for protected localities is that one can expect to find a relatively large number of one-year old threadlike green algae; the same as in areas with organic loading. At moderate organic loading it can therefore be very difficult to decide if the algal community is due to organic loading, protected localities or low salinity.

It is on this basis still probable that the increased occurrence of threadlike algae at the farms were due to organic loading. However, this effect on littoral communities was very local.

All the nine farms studied were visually very similar in the

effect on the littoral In general the effect was very local, and in a distance of 20 to 30 m from the farms the visual effects on the littoral had disappeared.

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